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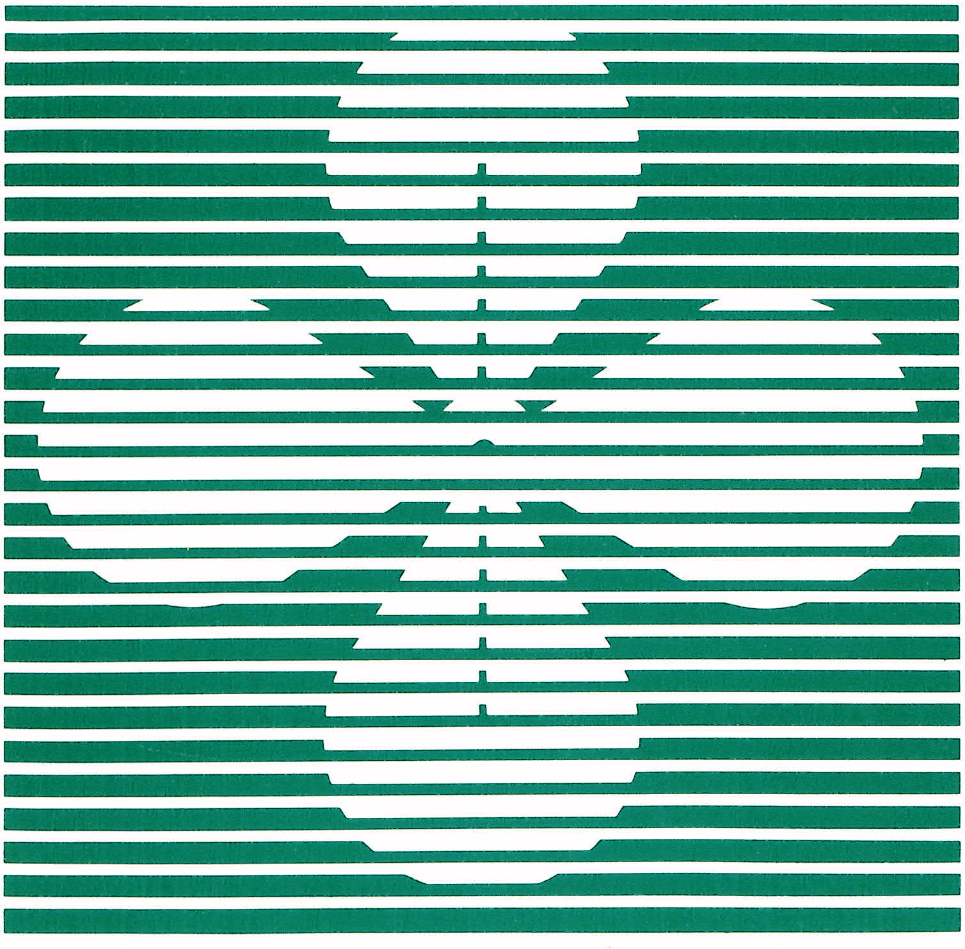
Laboratory Ventilation Work Book



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2nd Edition

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Acknowledgments

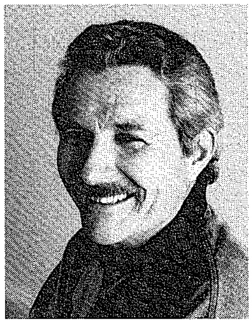
Hundreds of people have spent countless hours researching, investigating, and reporting laboratory ventilation problems and solutions. I acknowledge their great contributions. — D. Jeff Burton

Disclaimers

Mention of equipment names and manufacturers is not an endorsement. Always investigate thoroughly before purchase.

We believe that this work is free of instructions or information that may cause injury or harm but we cannot guarantee it. Always obtain competent professional assistance.

Names and places mentioned in case studies are fictitious. Any similarity to real people or places is coincidental.



About the Author

D. Jeff Burton (BS, MS, PE, CIH, CSP) has degrees in mechanical engineering and industrial hygiene.

The author of five books, two columns, and four home study programs, Jeff is also known for his excellent training courses and right-on consulting services.

Since 1974, he has participated in hundreds of ventilation design and evaluation projects.

Jeff is a past member of the national Board of Directors of AIHA and is a current member of ASHRAE, ASSE, AIHA, and ACGIH. He has served as a member of the Industrial Ventilation Committee of ACGIH, the Engineering Committee of AIHA, and the ANSI Z9.5 Subcommittee for Laboratory Ventilation.

Chapter 1.
Introduction

People

This book summarizes laboratory ventilation issues, but I hope you'll sense that it's more than just about ventilation of labs. I hope you'll sense that it is about people who work in labs; it's really about their health and well-being. It is about family members and their reliance on the person who works in the lab.

I haven't seen any statistics, but over the years, thousands of laboratory workers have suffered illness, injury, or discomfort from inadequate laboratory ventilation.

To register with Chemtrec, or to obtain safety information, MSDS sheets, and so forth from CMA, call:

800-262-8200

Chemtrec registration allows the user to attach the emergency spill number to MSDS sheets, shipping documents, and so forth. As of November, 1993, the registration cost was $500.

Right up front, let's give a number you can call if an emergency occurs (e.g., a chemical spill, the most common emergency). A 24-hour hotline is available from **Chemtrec** which is sponsored by the chemical industry: (75)

1-800-424-9300

The Appendix provides a checklist for other information and emergency phone numbers. (See Checklist No. 18)

You've noticed already—this *Workbook* is different from conventional technical manuals. It is written in a friendly "you and I" format and minimizes "scholarly treatments."

Types of readers

I expect a wide range of readers—HVAC engineers, nurses, building managers, lab safety engineers, industrial hygienists, lab chemists, and so forth. So please don't be too critical if some parts seem too simple, or some too complex, or some irrelevant. Just take what you need.

Basic approach

You may be tempted to read only those chapters related to your needs. I suggest you review the whole workbook first. (It will take only a couple of hours.) Then, study those chapters of most use to you.

Reasons for using this workbook

You may be part of a design team and will need to review plans and specifications. This book has a chapter devoted to this topic. You may be evaluating an existing facility, or troubleshooting a deficiency. Perhaps an existing lab is to be remodeled and you are expected to make suggestions. Maybe you are supposed to come up with a management plan for ventilating a lab. There are chapters on these topics, as well.

Coverage

We'll be covering today's common labs—the general chemistry lab and its equipment. But we'll also touch on specialty areas: glovebox hoods, perchloric acid fume hoods, bio-safety cabinets, hazardous materials labs, and so forth. Detailed information concerning these special topics can be found in references shown in the Appendix section **More Information.**

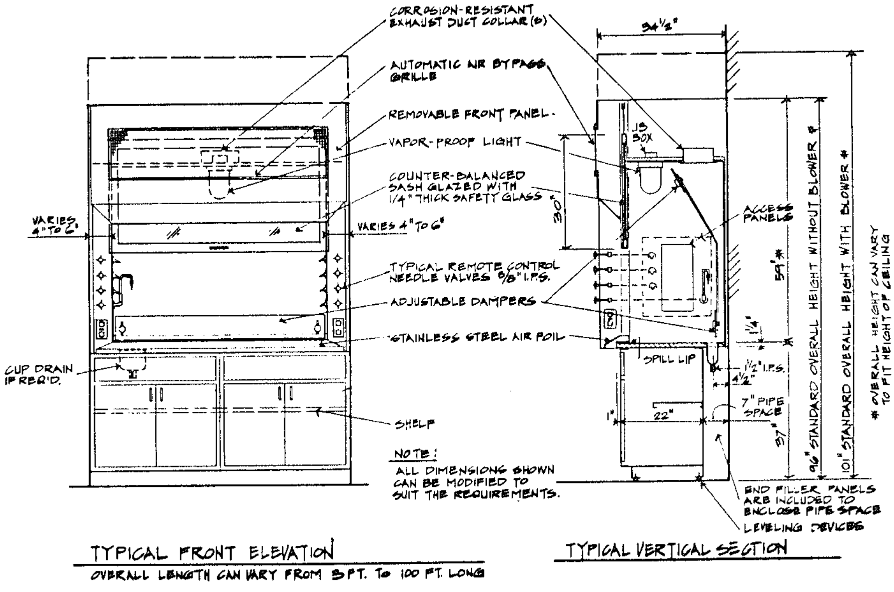
Sources of information

You won't see a lot of footnotes, but I give credit to people where I use something they said or wrote. I use a number in parenthesis (e.g., "(1)") to indicate the source, which is described in the Appendix section **More Information.** For example, on the last page you saw:

> A 24-hour hotline is available from **Chemtrec** which is sponsored by the chemical industry: (75)

The "(75)" refers to Reference 75.

Some of the figures in the workbook were adopted from equipment sales literature. Names and addresses of major manufacturers and suppliers are listed in the Appendix.

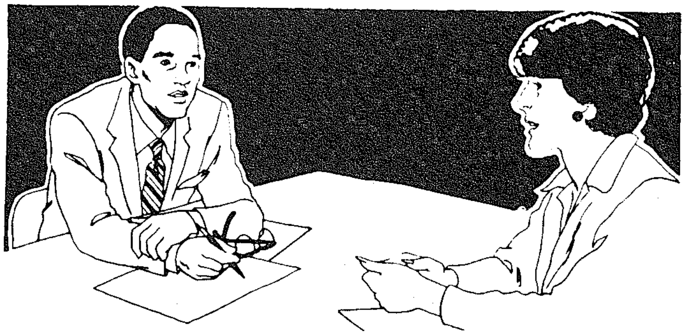

CORROSION-RESISTANT EXHAUST DUCT COLLAR (6)
AUTOMATIC AIR BYPASS GRILLE
REMOVABLE FRONT PANEL
VAPOR-PROOF LIGHT
COUNTER-BALANCED SASH GLAZED WITH 1/4" THICK SAFETY GLASS
VARIES 4" TO 6"
VARIES 4" TO 6"
TYPICAL REMOTE CONTROL NEEDLE VALVES 3/8" I.P.S.
ADJUSTABLE DAMPERS
STAINLESS STEEL AIR FOIL
CUP DRAIN IF REQ'D.
SHELF
NOTE: ALL DIMENSIONS SHOWN CAN BE MODIFIED TO SUIT THE REQUIREMENTS.
TYPICAL FRONT ELEVATION
OVERALL LENGTH CAN VARY FROM 3 FT. TO 100 FT. LONG
34 1/2"
JB BOX
30"
ACCESS PANELS
58"*
1 1/4"
SPILL LIP
1 1/2" I.P.S.
4 1/2"
7" PIPE SPACE
1"
22"
37"
96" STANDARD OVERALL HEIGHT WITHOUT BLOWER *
101" STANDARD OVERALL HEIGHT WITH BLOWER *
* OVERALL HEIGHT CAN VARY TO FIT HEIGHT OF CEILING
END FILLER PANELS ARE INCLUDED TO ENCLOSE PIPE SPACE
LEVELING DEVICES
TYPICAL VERTICAL SECTION

The Appendix starts on page 281

Sometime, check out the Appendix. It contains forms, charts, and checklists you can use. Actually there are two sets of checklists. The second set is for the workbook's exercises. (This preserves a clean copy for your future use.)

If you haven't used the *IAQ and HVAC Workbook*, you'll soon meet Ted and June, both of whom work for the consultation program of a county health department. Ted is about 30 years old; June, forty something. They both have bachelor degrees in the sciences—Ted in engineering, June in biology and nursing. Both are married with children. They work in Unitah County, Virginia, not far from Washington DC.

Case studies are *composites* of real situations. Names and places have been changed. They're written to be simple and interesting, but don't be fooled—they contain many details you'll need to solve similar problems.



Example problems always precede the exercises

Exercises often contain new information. For that reason, it is important that you work (or at least read) every exercise. Answers to exercises are found at the end of each chapter. (Try working the exercise before reading the answer.)

Expectations and objectives

After you have completed the *Workbook,* you will be able to:

- Talk confidently with others about the subject.
- Recognize laboratory ventilation problems and identify their potential causes.
- Relate specific complaints to potential sources.
- Use questionnaires and other paper instruments to evaluate laboratory ventilation problems.

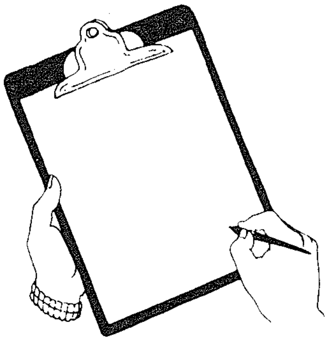
Objectives, continued

- Understand the basics of air behavior.
- Recognize and evaluate different types of laboratory HVAC systems.
- Recognize, choose, and evaluate lab fume hoods.
- Understand and use existing consensus standards.
- Understand government codes and activities.
- Assist in the control of lab ventilation problems.
- Develop your own in-house lab ventilation program.
- Develop your own in-house standards.
- Deal with employees and the public on lab ventilation issues.
- Develop and provide training to laboratory workers.
- Test laboratory ventilation systems.
- Set up real-time monitoring systems.
- Take certification exams with confidence.

Case Study

Multiple Causes

Space for your notes:



June leaned back to a more comfortable position in her chair. Unitah County government work required a lot of desk time—forms, records, reports, and the like. Long spells of desk work took its toll on her neck and back, although she rarely spoke about it. A pleasant woman, a true intellectual, she was popular among her co-workers. Her black hair was streaked with middle-aged gray and offset a pair of brown eyes, lately tucked behind new reading glasses. She moved her head down and looked at Ted over the top of the frame. She said simply, "Hi." Though speaking softly, she always had the attention of anyone in the room. A Jamaican by birth, she had been educated at New York City College, and her voice and syntax were stunning in their quality and simplicity.

"Have you got all the details for us to review?" She asked Ted.

Ted nodded. The others in the room looked his way with anticipation. Ted reached for his files. He and June had been working together at the County for almost five years, specializing in health and safety problems.

During the past several years, regular requests from local labs had kept the staff busy responding. June believed new standards and codes had generated a lot of interest in ventilation. Everyone was trying to upgrade their Chemical Hygiene Plan and comply with the new ANSI Z9.5 standard on lab ventilation.

“I’m glad you’re all here,” Ted said, taking a notepad from a manila file. “I’ve gathered a lot of data, and I’ll need your help if we’re to find out what’s happening.”

A request had come from the local college’s chemistry department. A small lab in the basement doing government contract work had been shut down for several days after employees complained of conditions in the lab. Ted had been sent to investigate. It was the kind of work Ted enjoyed. A tall red-head, slightly on the heavy side, and a conservative dresser, Ted was known for his good humor and patience. He was also a meticulous data gatherer.

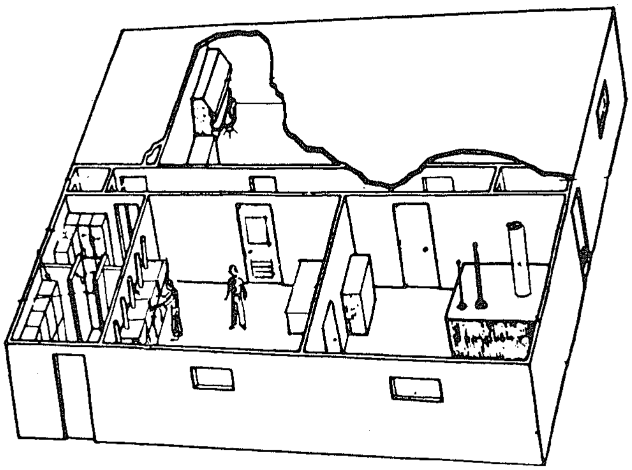
“There are two lab technicians and one student working at two hoods in this lab module. They’re running tests on water samples; no hazardous chemicals are used,” Ted reported. “All three people had severe headaches this past Friday. And that wasn’t the first time. Seems they’ve been complaining of headaches and other maladies all winter.”

“It might be carbon monoxide,” June said. “Any sources of CO?”

“Well, not that I could see,” Ted replied. “The lab is in the basement, near store rooms, and other small labs. It sits along the north wall, and next to it is the Mechanical Room...water heaters, small boiler, incinerator, and so forth. The lab is heated by steam heaters. A small make-up air unit on the roof brings replacement air to the room, about half of it, that is. The other half of the make-up air comes from the hallway through a louver in the door. I don't think it meets our fire code, but that wouldn't solve the problem we have—headaches and other complaints." Ted stopped to look through his notes.

"Speaking of fire codes, where are the exits for the lab?" June asked.

"Yes, just a minute...here's a schematic view of the as-builts," Ted said, holding up a small roll of prints. "There are two doors, one at the hall on the south side of the room, and one on the north-west wall that enters the Mechanical Room. I guess people can escape through the Mechanical Room if there's a fire in the front of the lab."



Exercise No. 1. From the data given so far, what comes to mind as a potential source of the trouble? (Note: Answers to exercises are provided at the end of each chapter. Please write your answer below. It is best not to refer to the Answer Section until after you have finished reading the Case Study.)

Case study, continued.

"Did you check the make-up air? What else did you notice?" June asked. Something was obviously on her mind.

"Well, the make-up air was on, but it was supplying only about one-tenth of the exhaust air. The hoods were exhausting about 3,000 cubic feet per minute, and the make-up air system was supplying about 300 cubic feet per minute of outdoor air. The rest was coming from the hallway, I guess." Ted paused. "As for other things, the hoods were working fine—no observable emissions using smoke. No obvious sources of carbon monoxide or solvents that could have caused headache. The employees complained of smoke. I didn't smell it myself, but you know me, I'm a terrible smeller."

"You smell terrible? Is that what you said?" June asked, getting a groan from the group. "What about the room pressure?"

"Yes, that is a problem. There is a heavy negative pressure in the room. The door swings out into the hallway. It is very difficult to open. The louver in the door has been mostly blocked with a poster...some football poster, or something."

Exercise No. 2. From the data given so far, what now comes to mind as a potential source of the trouble?

"Well, I've got a theory," June said. "Replacement air has to be coming from someplace. If it is not coming from the make-up air system or the hallway, then it might be coming from the Mechanical Room through the door connecting the two rooms. If the Mechanical Room is also under negative pressure, it could be drawing flue gases back down the chimneys and stacks. The smell of smoke obviously suggests a combustion source. And where there's smoke, there is likely to be carbon monoxide."

"You're right," Ted said. "And the end-of-the-week headaches suggest carbon monoxide."

"Why don't you check that out, and get back to us," June suggested.

Exercise 3. If you were in Ted's shoes, what would you do to check it out?

Several days later, Ted appeared in June's doorway. She stood, motioning him to have a seat. She came around the sat beside him. They had been through a lot together these past five years and made a good team. "I bet you've got it solved. I see that look of satisfaction on your face," June said.

"You were right," Ted reported. "Air was coming through the Mechanical Room. Some time during the fall, the outside air louver to the Mechanical Room was blocked to avoid freezing the pipes. You remember that really cold spell we had in November?"

June nodded. It had frozen some fruit she had stored in the garage.

"Well, both rooms were starved for air. So air was coming in through the water heater vent pipe and the incinerator stack. Thus the smoke, and the carbon monoxide. And I measured for it—it was running about 200 ppm at the time."

"What are they doing about it?" June asked.

"Well, the short term fix was easy." Ted responded. We took the poster off the front door. It made a big difference. Joe—the building mechanic—is getting the Mechanical Room outside air louver opened, and having the combustion equipment checked. But the long-term fix will require an appropriation of next years funds. They're going to provide a new make-up air system to supply ninety percent outdoor air to the room."

"Thanks, Ted. Good job. It is amazing how these things happen," June mused.

They departed for coffee.

Exercise No. 4. Suggest a probable chain of events which led to the complaints. How could they have been avoided?

Answer Section

Exercise No. 1. From the data given so far, what comes to mind as a potential source of the trouble?

Carbon Monoxide often suggests incomplete combustion. The mechanical room (next door to the lab!) contains equipment which burns fuel. It may only be a coincidence, but it would be worth looking into.

Exercise No. 2. From the data given so far, what comes to mind as a potential source of the trouble?

The smell of smoke and the tightness of the room strongly suggests a combustion source coming from an adjacent space to the lab. Again, the Mechanical Room seems a likely culprit.

Exercise No. 3. If you were in Ted's shoes, what would you do to check it out?

Depending on your expertise, you might want to call in an industrial hygienist or safety professional to monitor for carbon monoxide. To check out the Mechanical Room, you'd want to involve the building mechanic, and get him/her to explain the equipment, and check it out for you. At this point in our *Workbook,* we can't be too specific. But when you have finished, you'll be much more knowledgeable about what to do, what to look for, and how to solve the problem. (However, we can never hope to do it all by ourselves.)

Exercise No. 4. Suggest a probable chain of events which led to the complaints. How could they have been avoided?

Your list is as good as any. Here is one: 1. The replacement air system was originally undersized; perhaps fire codes were not met. 2. A poster was hung over the inlet louvers on the front door, drawing air into the lab through the mechanical room from the outside air louvre. 3. Cold air coming into the Mechanical Room froze some pipes during the winter. 4. The outside louver was blocked to stop infiltration of cold air to the Mechanical Room, thus starving the hoods, and creating a negative pressure in both rooms. 5. Air was drawn down exhaust stacks, introducing flue gases into the space.

A good approach to avoiding a negative chain-of-events is to train people to understand how the system operates. A lab technician or student is likely to be oblivious to the workings of the various ventilation systems in the lab. It is a good idea to show employees and students exactly how the system is designed to operate. Then, when changes occur, the user may be better prepared to recognize and avoid problems, or identify their causes after they have occurred.

Chapter 2.
Important words

I hate to put boring stuff up front, but there is a tedious chore before we can proceed—learning a few terms, like *fume cupboard.*

Every discipline has its own jargon. If you're to deal with something foreign, you have to know the language.

So, take about ten minutes and simply read the following paragraphs. Skip those you already know. You won't remember everything, but you'll have a base from which to build.

Check those you don't know √

A more complete list of definitions is located in the **Glossary** in the Appendix.

A&E. The "architect and engineer." Generic term refers to designers of laboratory buildings and ventilation systems.

acceptable indoor air quality. Air in which there are no known contaminants at harmful levels as determined by appropriate authorities, *and* air with which 80% or more of the people do not express dissatisfaction.

ACH, AC/H (Air Changes per Hour), N. The number of times air is theoretically replaced in a space during one hour.

AHU (Air Handling Unit), air handler. Refers to the ventilation equipment in HVAC systems.

air conditioning. The process of treating air to meet the requirements of a conditioned space by controlling its temperature, humidity, odor, cleanliness, and distribution.

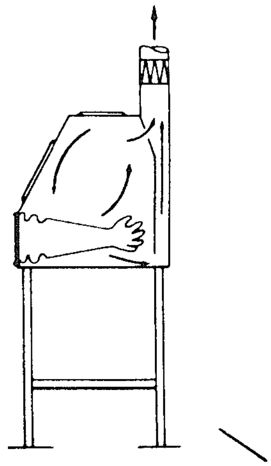
air density (also weight density). The weight of air in pounds per cubic foot. Dry standard air at T = 70 degrees F, BP = 29.92 inch Hg has a weight density of 0.075 lbs/cu ft.

anemometer. A device which measures the speed or velocity of air. Common types include the *swinging vane* and the *hot-wire* anemometer.

Area, A. The cross-sectional area through which air moves. The area could be the cross-sectional area of a duct, a lab fume hood, a door, or any space through which air moves. Units, square feet, sf.

ASHRAE. American Society of Heating, Refrigeration, and Air Conditioning Engineers. Primary association involved in IAQ, filtration, and comfort ventilation.

atmospheric pressure. The pressure exerted in all directions by the atmosphere. At sea level, the mean atmospheric pressure is 29.92 inch Hg, 14.7 psi, 407 inch w.g., or 760 mm Hg. Also, Barometric Pressure, or Absolute Static Pressure.



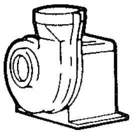
bio-safety cabinet. A hood to control the dissemination of viable or non-viable particles of biological origin, microorganisms and their decay products.

Most preferred: **bypass lab fume hood.** A lab fume hood constructed such that as the sash closes, air is allowed to bypass the hood face through another opening, usually above the sash. The bypass hood provides for a reasonably constant face velocity and hood static pressure.

dilution ventilation (also, general exhaust ventilation). Air quality control which relies on the dilution of airborne contaminants, usually by using outdoor air. (OA.)

ductless lab hood. A hood which filters exhaust air and returns it to the lab environment.

face velocity. The rate of flow per square area (cubic feet per minute per sq ft of hood open face area), or the velocity (feet per minute) of air moving through the open area of a lab fume hood.



fan. A mechanical device which physically moves air and creates static pressure.

fan curve. A curve relating pressure vs. volume flow rate of a given fan at a fixed fan speed (rpm).

friction loss. The static pressure loss in a system due to friction; expressed as inches w.g. per 100 feet, or fractions of VP per 100 feet of duct (SI: mm w.g./meter; K/meter).

fume cupboard. British term for laboratory fume hood.

gauge pressure. The difference between two absolute pressures, one of which is usually atmospheric pressure (e.g., "1.0 inch w.g.")

glovebox lab hood. An enclosed, six-sided hood with arm-length gloves provided at the front or side of the hood for access. An air-lock pass-through port is often provided to insert and remove materials from the hood.

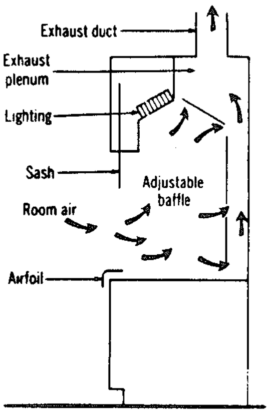
hood static pressure. The static pressure near a hood in the duct serving the hood; measured static pressure about 2-5 duct diameters downstream in the duct near a hood.

HVAC. "Heating, Ventilating, and Air Conditioning," "H-Vac;" Air handling systems designed primarily for temperature, humidity, odor control, and air quality.

indoor air quality, IAQ. The study, evaluation, and control of indoor air [as related to the quality of temperature, humidity, odor, and cleanliness.]

inches of water, "inch w.g." A pressure term. One inch of water is equal to 0.0735 inches of mercury, or 0.036 psi. Atmospheric pressure at standard conditions is 407 inches w.g. (water gauge.)

industrial ventilation, IV. The equipment or operation associated with the supply or exhaust of air, by natural or mechanical means, to control airborne hazards in the industrial setting.



infiltration. Air leakage into a space through cracks and interstices, and through ceilings, floors, and walls.

laboratory ventilation. Air-moving systems and equipment which serve laboratories.

laboratory hood. A ventilated enclosure designed to capture, contain, control, and remove gases, vapors, and particles generated within the enclosure.

laminar flow, also streamline flow. Ideally, air flow in which air molecules travel parallel to all other molecules; flow characterized by the absence of turbulence.

local exhaust ventilation. A ventilation system which captures and removes emitted contaminants before dilution into the ambient air. A lab fume hood system is considered a local exhaust ventilation system.

loss. Usually refers to the conversion of static pressure to heat, noise, or vibration in components of the ventilation system, viz., "the hood entry loss."

make-up air. See replacement air.

manometer. A device which measures pressure difference; usually a U-shaped glass tube containing water, oil, or mercury.

outdoor air (OA). "Fresh" air mixed with return air (RA) to dilute contaminants in the supply air (SA); outdoor air is usually obtained from outside the building, but exceptions exist (e.g., from an acceptable hallway).

pitot tube. A device used to measure pressures in an air stream.

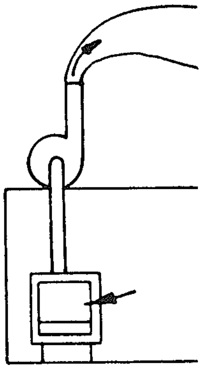
plenum. A low-velocity air chamber used to distribute static pressure throughout its interior.

pressure drop. The loss of static pressure across a point; for example, "The pressure drop across the elbow is 0.40" w.g."

relative humidity, RH. A measure of the amount of water vapor in air. A relative humidity of 100% is about 2.5% total water vapor in air, by volume.

replacement air (also, make-up air.) Air supplied to a space to replace exhausted air.

return air, RA. Air which is returned to the fan from the occupied space for recirculation.



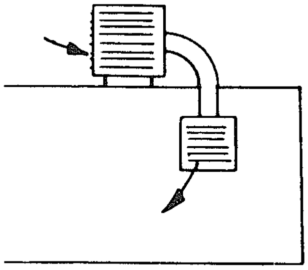
sash. A moveable panel or door set in the hood entrance to form a protective shield and to control the face velocity of air into the hood.

stack. The device on the exhaust end of a ventilation system which disperses contaminants for dilution by the atmosphere.

standard air, standard conditions. Dry air at 70° F, 29.92 inch Hg; or, air at 50% relative humidity, 68° F, and 29.92" Hg; in either case, the air density = 0.075 lbs/cu ft.

static pressure, SP. The pressure developed by a fan; SP exerts influence in all directions; the force in inches of water measured perpendicular to flow at the wall of the duct; the difference in pressure between atmospheric pressure and the absolute pressure inside a duct, cleaner, or other equipment.

suction pressure. See static pressure. (Archaic. Refers to static pressure on upstream side of fan.)



supply air, SA. Air supplied to a space from the air handling system.

variable air volume, VAV. Refers to ventilation systems in which the air volume is varied by dampers or fan speed controls to maintain constant conditions; primarily used for energy conservation.

velocity, V. The time rate of movement of air; feet per minute.

volume flow rate, Q. The quantity of air flowing in cubic feet per minute.

Exercise. Please define the following in your own words:

Laboratory Indoor Air Quality

Bypass Lab Fume Hood

Outdoor air

Plenum

Face Velocity

Sash height

Check your answers against the text.

Chapter 3.
Air Behavior

Because air is the very basis of laboratory ventilation, it is useful to know something about how air behaves.

We all know air—we were born into it. It is an integral part of our lives. But do you really know what it is?

Exercise 1. Place list the major components of air in the proper order by approximate volume.

1. Nitrogen, 78%

2.

3.

4.

5.

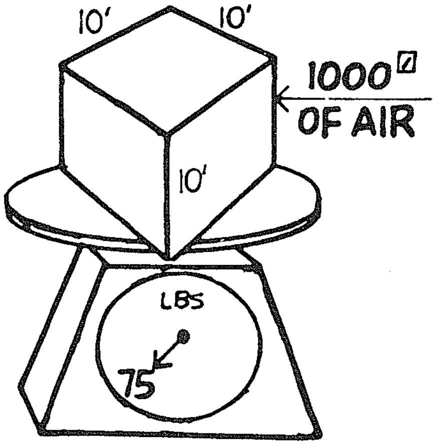
Did you know that water vapor was the third most prevalent material (most of the time)? That carbon dioxide was the fifth most prevalent (about 350 ppm by volume in air) after Argon?

Soup

Air is a rapidly mixing, soupy physical material. And like other materials, air has mass and weight. It also has density, temperature, viscosity, and on and on. Lets explore each parameter and see how it effects air's behavior.

Weight density

Air has a density of 75 lbs per 1,000 cubic foot at standard conditions (STP). (See below for the definition of standard conditions.) Water, for comparison, weighs about 62,400 lbs/1,000 cu.ft.



The weight density is written w = 0.075 lbs/cu ft.

Specific gravity

The ratio of the mass of a gas or vapor to the mass of an equal volume of air is called the *specific gravity* of that gas or vapor. For example, carbon monoxide has a specific gravity of 0.968, which means that carbon monoxide CO weighs 96.8% of the weight of air.

Similarly, the ratio of the mass of a liquid or solid to the mass of an equal volume of water is called the *specific gravity* of that liquid or solid. For example, carbon tetrachloride has a specific gravity of 1.595. This means that one cubic foot of carbon tetrachloride weighs 1.595 • 62.4 pounds = 99.5 lbs (rounded).

Please find and review the Chart.

Chart No. 4 provides a list of specific gravities and molecular weights for common solvents and gases.

Molecular weight

Air has a composite molecular weight of about 29.0. Carbon dioxide has a molecular weight of 44.

Standard conditions, STP

Air at sea level is considered close to "standard." [Sometimes it is also referred to as "normal conditions," NTP.]

Because the definition of "standard" varies, always check the source for the exact definition.

More specifically, STP is air at a barometric pressure of 29.92 inches Hg, a temperature of 68° Fahrenheit, and 50% relative humidity. When the air is dry, STP is 29.92 inches Hg, a temperature of 70° Fahrenheit, and 0% relative humidity. In the SI system, STP is 21° C at 760 mm Hg.

For ventilation, air at standard conditions always has a weight density of w = 0.075 lbs/cu ft.

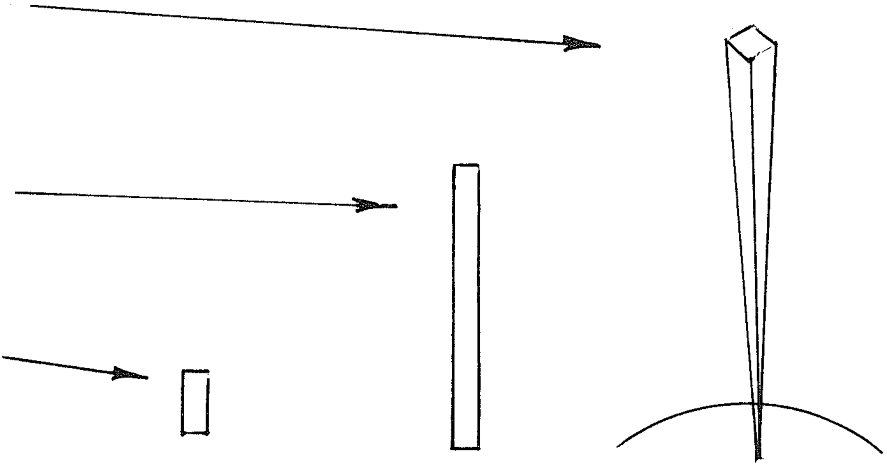
Incidentally, we assume standard conditions for all examples and exercises in this *Workbook.* Please see Chapter 20 for dealing with non-standard conditions.

Air pressure

Pressure is defined as force per unit area. For example, sea level pressure is often given as 14.7 lbs per square inch, psi. In familiar terms, this means that a cross-sectional square inch of air reaching from the surface of the earth to the top of the atmosphere weighs 14.7 pounds. This is the same weight as a similar one-inch square column of water 407 inches in height, and a similar column of mercury 29.92 inches in height. See the next figure.

When the atmospheric column of air gets lighter, i.e., when its density drops, its ability to hold up a column of mercury or water also decreases. Thus when a low pressure weather pattern goes through the area, the barometric pressure may drop to 29.7 inches Hg, etc.

In lab ventilation, pressure is normally measured in *inches (or millimeters) of water*, with 407 inches of water being the absolute pressure at standard conditions (i.e., 407 inches of water = 29.92 inches of mercury).



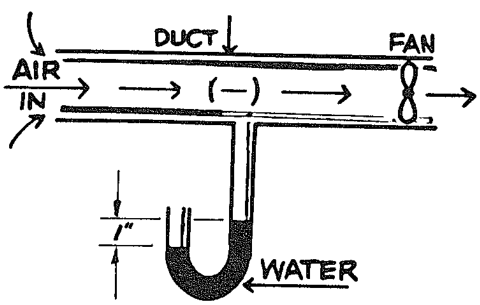
A one square inch column of air rising from sea level to the top of the atmosphere, weighs 14.7 lbs (6.67 Kg).

An equivalent column of water weighing 14.7 lbs is 407 inches in height.

An equivalent column of mercury is only 29.92 inches high.

Pressure causes movement

In the atmosphere, pressure differences create movement of air masses—wind. Atmospheric pressure pushes air from a high pressure area to a low one. (Nature abhors a vacuum.) In a lab hood, air is induced to move by a pressure difference created by the fan. In the next figure the fan lowers the atmospheric pressure, creating one inch of negative gauge pressure called "static pressure." Atmospheric pressure pushes air into the duct in order to equalize the pressure. A U-tube manometer filled with water measures the gauge static pressure. "Static pressure" is essentially the same as "barometric pressure." Both create pressure in every direction and both can be measured in inches of water.



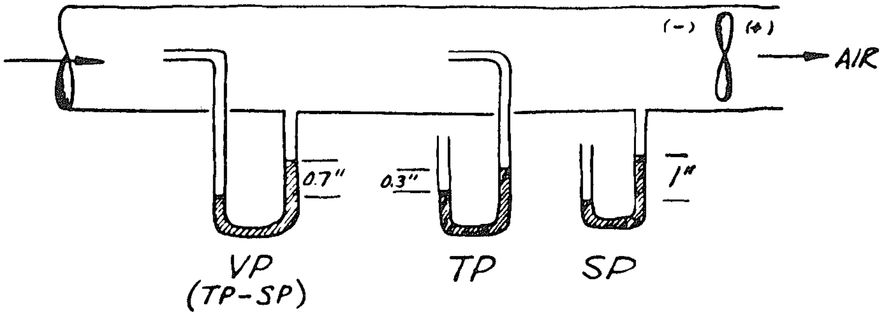
Static Pressure, SP

Static Pressure (SP) is created by the fan. SP is felt in all directions within the duct, and is measured in such a way that the flow of air does not effect the measurement, as shown in the next figure. Negative static pressure tends to want to collapse the duct. Positive static pressure wants to blow it up like a balloon.

Total Pressure, TP

Velocity Pressure, VP

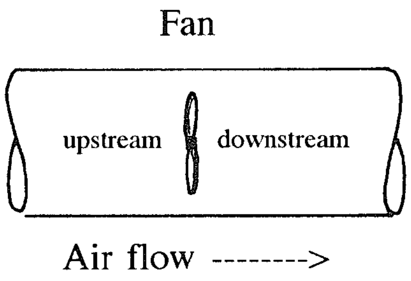
If the end of the manometer probe is inserted facing directly into the air stream, the manometer will not only measure static pressure, but will also measure the influence of the air impacting on the end of the probe. (Imagine billions of air molecules crashing against the dead air space in the probe. This creates pressure.) This combination of pressures is known as the "impact" pressure, or the total pressure (TP). The pressure component solely attributed to the impacting molecules is called the Velocity Pressure (VP). The Velocity pressure can be estimated by subtracting the static pressure from the total pressure.



In order to make calculations using the pressure formula

$$TP = SP + VP$$

the sign of each term must be known and used. Any time the static pressure within the duct is less than the atmospheric pressure, it is negative. If the pressure is greater than atmospheric pressure, the sign is positive. The table in the next figure shows the sign normally found on the upstream and downstream side of the fan.



	TP	SP	VP
Upstream of fan	–	–	+
Downstream of fan	+	+	+

$$TP = SP + VP$$

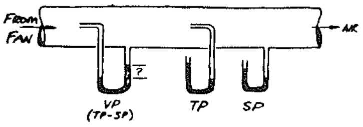
Example 1. Determine the velocity pressure, VP. Use relationships in the figure above.

TP = -0.35" w.g. SP = -0.50" w.g.

TP = SP + VP

and

VP = TP - SP = -0.35 - (-0.50) = 0.15" w.g.



Exercise 2. Determine the velocity pressure, VP. Use relationships in the figure above.

TP = +0.75" w.g. SP = +0.50 " w.g.

Volume flow rate, Q

The volume flow rate of air at any point in a ventilation system can be described by the equation shown on the next page. The most common US units are these: Area is given in "square feet," velocity is described in terms of "feet per minute." Multiply these two terms together, and you get cubic feet per minute, or volume flow rate. Volume flow rate is designated by "Q" and is the product of the velocity and the area.

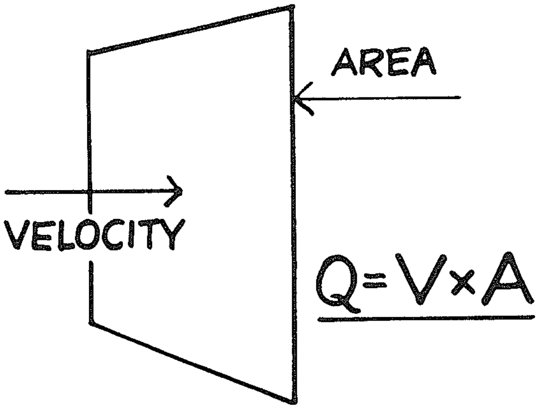
$Q = V \bullet A$ cfm (cu m/sec, metric units)

where

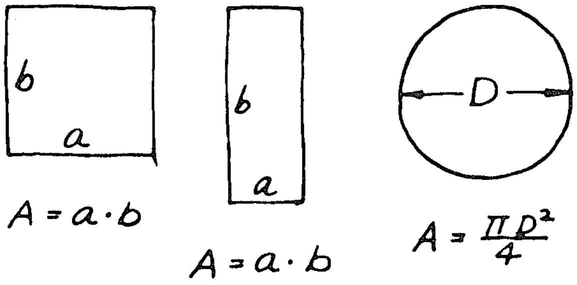
V is velocity, fpm (m/sec)
A is cross-sectional area, square feet (sq meters)

We assume incompressible flow in almost all lab ventilation systems.

The units "cfm" are usually written as scfm (flow at standard conditions) or acfm (flow at actual conditions.) If you want to enhance your professionalism, always write scfm or acfm.



The cross sectional area of a lab fume (or a duct, or a door) is given by the formulas in the next figure.



Example 2. The cross-sectional area of a lab fume hood duct is A = 0.7854 sq.ft. The velocity of air flowing in the duct is V = 2250 ft. per minute. What is the flow rate, Q?

Round the last number to reflect the minimum number of significant figures in the input data (e.g., 2,250 has three significant figures so round Q to 1,770.)

$$Q = V\ A$$

$$= 2250 \text{ fpm} \bullet 0.7854 \text{ sq.ft.}$$

$$= 1770 \text{ scfm}$$

Exercise 3. The cross-sectional area of a lab fume hood duct (diameter = 10") is A = 0.5454 sq.ft. The average velocity of air flowing in the duct is V = 1875 ft. per minute. What is the flow rate, Q?

Use the flow formula and the area formulas.

Velocity and Velocity Pressure

Several centuries ago, a man named Bernoulli described the relationship between velocity pressure and velocity. After adjusting for our units, the relationship at standard conditions is given by

$$V = 4005\ (VP)^{1/2} \qquad (= 4.043\ (VP)^{1/2}, \text{ metric})$$

The velocity pressure, VP, is given in inches of water, "inches w.g." (mm w.g), and V is feet per minute, fpm (m/sec). The figure "4005" incorporates the conversion factors, density, and so forth.

Example 3 The velocity pressure of an airstream in a lab fume hood duct is 0.33 inches w.g. What is the velocity?

$$V = 4005\ (VP)^{1/2} = 4005\ (0.33")^{1/2}$$
$$= 2300 \text{ fpm}$$

Conversion at STP

VP, inch	V, fpm
0.01	401
0.02	566
0.03	694
0.04	801
0.05	896
0.06	981
0.07	1060
0.08	1133
0.09	1202
0.10	1266
0.11	1328
0.12	1387
0.13	1444
0.14	1499
0.15	1551
0.16	1602
0.17	1651
0.18	1699
0.19	1746
0.20	1791
0.22	1879
0.25	2003
0.28	2119
0.30	2194
0.35	2369
0.40	2533
0.45	2687
0.50	2832
0.55	2970
0.60	3102
0.65	3229
0.70	3351
0.75	3468
0.80	3582
0.85	3692
0.90	3799
0.95	3904
1.00	4005

Example 4. The static pressure is measured in a 10-inch square duct to be SP = -1.05 inch w.g. The total or impact pressure is TP = -0.75 inch w.g. What is the velocity and volume flow rate of the air flowing in the duct? (STP. Please see Chapter 20 for non-STP.)

Area, A = 10" x 10" / 144" per sq ft = 0.6944 sq ft

VP = TP - SP = -1.05" - (-0.75") = 0.30" w.g.

Velocity, $V = 4{,}005\ (VP)^{1/2} = 4005\ (0.30)^{1/2}$
$= 2{,}194$ fpm

Volume flow rate, $Q = VA = (2{,}194)(0.6944)$
$= 1{,}500$ scfm (rounded)

Exercise 4 The static pressure in a 12-inch square duct is SP = -1.10 inch w.g. The total or impact pressure is TP = -0.85 inch w.g. What is the velocity and volume flow rate of the air flowing in the duct? (At STP.)

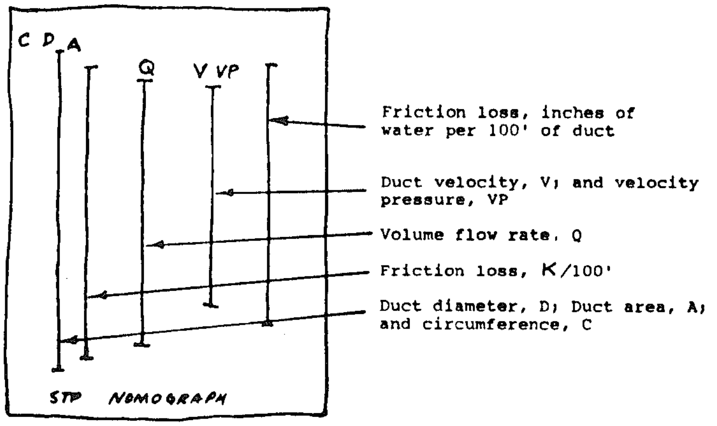
Use all of the formulas introduced to this point. In your work, carry the units and terms along.

The Nomograph (Chart no. 5)

On Chart No. 5 you will find a nomograph that solves duct area problems, Bernoulli's equation, and the Q = VA equation.

The figure on the next page shows how the Nomograph is set up. Study it, then do **Exercise 5** using the Nomograph. (We will discuss the "friction loss" in a few pages.)

Please find the extra Chart 5 in the back of the book, tear it out, and bring it up here for use.



Friction loss, inches of water per 100' of duct

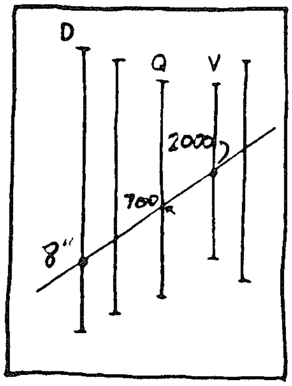
Duct velocity, V; and velocity pressure, VP

Volume flow rate, Q

Friction loss, K/100'

Duct diameter, D; Duct area, A; and circumference, C

Example 5. Find Q, the volume flow rate, for air moving at V = 2,000 fpm in an eight-inch round duct. Use the Nomograph. Locate D = 8". Locate V = 2,000 fpm velocity line. Draw a straight line and read Q = 700 scfm.



Exercise 5. Find Q, the volume flow rate, for air moving at V = 1,500 fpm in a twelve-inch round lab hood duct. Use the Nomograph.

At STP each molecule is separated from its neighbor by about nine molecular diameters.

Air naturally mixes at very high velocities. (At the molecular level, air molecules are thought to have speeds in excess of 1,000 mph.) They don't go far, though, because they bump against other molecules. This and other forces create tremendous mixing.

The causes of this tremendous mixing are beyond the scope of the book, but it is nice to know that average mixing currents of about 20 fpm in "quiet" air are not unusual. In more energetic environments (such as might be found in labs), it isn't unusual to find "natural" mixing currents as high as 50 feet per minute.

We can't detect normal air mixing because our skin only begins to sense air movement at about 50 fpm on our necks and ankles, and at 100 fpm on our hands.

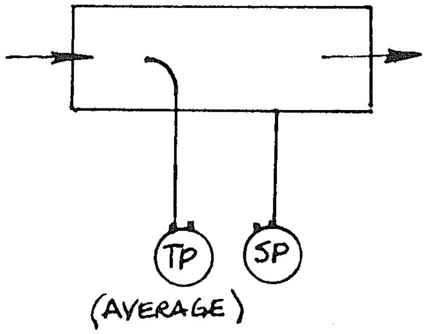
Many hoods are designed for face velocities of 80-100 feet per minute, not much more than typical mixing velocities found in many labs.

Try blowing softly on your hand so you just barely feel movement. That's about 100 feet per minute. Pretty slow, right?

Knowing something about air gives us an appreciation of the tasks ahead.

Answers to Exercises

Exercise 1. Nitrogen, oxygen-20.9%, water vapor-usually 1-2% by volume, argon-1%, carbon dioxide-usually about 340 ppm, and other gases and aerosols in trace amounts.



Exercise 2. Determine the velocity pressure, VP.

TP = +0.75" w.g. SP = +0.50 " w.g.

TP = SP + VP

and

VP = TP - SP = 0.75 - (+0.50) = 0.25" w.g.

Exercise 3.

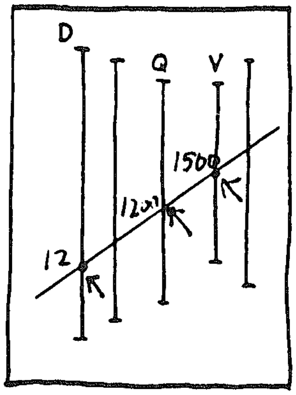
Q = V A
= 1,875 fpm X 0.5454 sq.ft.
= 1,020 scfm

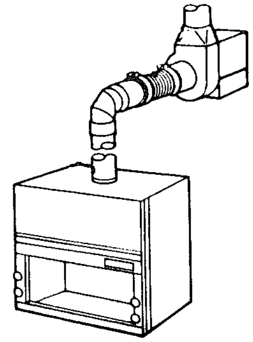
Exercise 4.

Area, A = 1' x 1' = 1 sq ft
VP = TP - SP = -1.10" - (-0.85") = 0.25" w.g.
Velocity, V = 4005 $(VP)^{1/2}$ = 4005 $(0.25)^{1/2}$ = 2000 fpm
Volume flow rate, Q = VA = (2000)(1) = 2000 scfm

Exercise 5.

Locate D = 12". Locate V = 1,500 fpm velocity line.
Draw a straight line and read Q = 1200 scfm





Chapter 4. Management of laboratory ventilation systems

Objectives

Ventilation is provided in a lab to control chemical emissions and exposures, and to provide a comfortable, safe, and healthful environment. None of this can be accomplished or maintained without management participation.

We have met management and it is us.

Regardless of your position, you are part of that management effort. You may be called upon, for example, to determine whether or not ventilation is required to control emissions and exposures, or whether existing ventilation is adequate.

Page 305

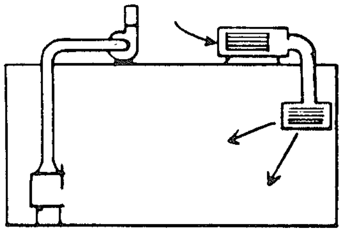
Form No. 1, *Laboratory Chemical Hazard-Potential Determination Worksheet* (see **Charts** section in the Appendix) provides a way for you to organize your evaluation of the hazard potential. You may need to bring in outside expertise to assist you (e.g., an industrial hygienist, toxicologist, and so forth.)

Extra charts and forms begin on page 339.

Exercise 1. Please find extra Form No. 1. If you have access to a lab, use Form No. 1 to evaluate a chemical and its usage in the lab. If you do not have access, simply review the form. Make comments below.

Ventilation both controls hazards and provides comfort.

To control a chemical hazard with ventilation, specific amounts of air are supplied to and exhausted from the lab. In order to provide comfort for lab occupants, odors, air temperature, and humidity are also controlled.



Exhaust systems are provided to capture, contain, and control chemical emissions, and to transport them out of the laboratory. Laboratory fume hoods are attached to fans by exhaust ductwork. Air cleaners and stacks may be provided to avoid reentry of exhausted chemicals to the building.

Air supply systems replace exhausted air and maintain appropriate pressures within the laboratory space. They also provide a measured amount of outdoor air and appropriate amounts of air exchange. Fugitive emissions from exhaust ventilation systems or other non-exhausted bench activities are also controlled by the supply system, which acts as a dilution ventilation system.

An HVAC (heating, ventilating, and air conditioning) *system* provides temperature and humidity control, and may be integrated into the supply/replacement air system. This is often called the *comfort ventilation system.*

Have you read **Chapter 3** which introduced you to the basics of air physics? If you haven't read that chapter, you should do so before proceeding.

This chapter introduces fundamental approaches to the design and operation of laboratory ventilation systems. Later chapters provide more detailed information.

Hoods

For example, Chapter 5 provides information on chemical laboratory fume hoods. Chapters 6, 7, and 8 discuss glove box hoods, perchloric acid fume hoods, and bio-safety cabinets.

High toxicity

Chapter 9 covers special requirements for the ventilation of labs handling highly hazardous materials.

Testing

Chapter 10 discusses ventilation testing and monitoring.

Hood static pressure

Chapter 11 expands on the use of hood static pressure monitoring.

HVAC

Chapter 13 introduces supply and HVAC systems.

Systems

Chapters 15, 17, and 18 discuss stacks, duct design, and fan selection.

Dilution

Chapter 16 discusses vapor generation and dilution exhaust air volumes. (A very valuable chapter.)

Generally accepted good management practices

Air exchange rates

The volume flow rate of air moving through a laboratory should be at least 1.0 to 2.0 cubic feet per minute per square foot of floor area. This translates to about 7-15 air changes per hour in most labs. Except where room heat loads are high, the air exchange rate is usually a function of the fume hood exhaust volume flow rate.

For example, a lab 12' by 20' by 8' with a lab fume hood exhausting 1,200 cfm creates 38 air changes per hour in the lab.

Air handling systems (AHU)

Lab air supply systems may often be part of a larger air handling system which serves other areas of the building (e.g., offices, lavatories, cafeterias, classrooms, and so forth). Generally, supply and comfort ventilation air serving a laboratory should not be recirculated (returned) to the building air handling system.

Generally, avoid recirculation.

The new ANSI Z9.5 standard for laboratory ventilation (See Chapter 12) allows lab room air to be returned to the central air handling unit when one of the following sets of criteria are met:

A. 1. There are no life-threatening materials in the lab, and
   2. air contaminants generated by the maximum credible accident bill be below hazardous concentrations, and
   3. the OA supply system is provided with reliability features.

or

B. 1. Recirculated air is treated to reduce contaminants to below hazardous concentrations, and
   2. recirculated air is constantly monitored, or provided with redundant cleaning devices, and
   3. a preventive maintenance plan is employed, and
   4. a bypass is provided to the return system to divert air to atmosphere when necessary.

Hoods: never recirculate

Air from hoods and other chemical exhaust systems should *never* be recirculated, except in limited, acceptable, and controlled circumstances.

Air pressure relationships

Most laboratory ventilation systems are designed and intended to provide a constant pressure between the lab and other labs and/or building areas. Usually the lab is under negative pressure with respect to office areas. The pressure difference is not great, usually ranging from -0.005" w.g. to -0.05" w.g.

Air moves from less hazardous areas to more hazardous areas.

More hazardous labs are kept negative with respect to less hazardous adjacent labs. This helps keep accidents and catastrophes from contaminating less-hazardous adjoining spaces. Where odors are a problem (e.g., animal handling facilities, autopsy labs), negative pressures will keep offensive odors from infiltrating adjacent spaces.

Clean rooms may require positive pressure

Where clean environments are required, the opposite pressure relationship can be used. For example, where a germ-free environment is required in an animal testing lab, the lab is kept under a slight positive pressure.

Weighted dampers are a simple approach for maintaining pressure differences between adjacent spaces.

These pressure relationship are developed and maintained by careful selection of supply and exhaust air volumes. Typically, a lab kept under negative pressure will have a supply air rate of 90% of the exhaust air volume flow rate. This requires the other 10% to be obtained from adjacent spaces, e.g, hallways, leaks in fixtures, windows, and so forth.

Supply air is usually a function of the exhaust rate, not the reverse. During design, supply volumes cannot be determined until exhaust rates are determined. In existing systems, supply rates should be adjusted to meet exhaust rate needs.

Use low velocity supply registers

The construction and location of supply air registers is important to the overall success of a lab ventilation system. High velocity registers create drafts and turbulence. At a lab hood face this turbulence may create excessive fugitive emissions. Typically, air supply registers should be sized for low inlet velocities (500-800 fpm), and terminal velocities of no more than 50 feet per minute (measured with the lab fume hood exhaust system turned off). Supply registers should not be installed directly over a lab fume hood, a common mistake. (See Chapter 13.)

Location of air intakes for the building air handling system and makeup air systems.

Air intakes for the supply system should not be located where entrainment of contaminated air is possible. Intakes should be placed on the lower 1/3 of the building, but not near parking areas, truck loading zones, garbage handling areas, and so forth. Air intakes should not be placed within 25 feet of cooling towers or 50 feet of hood exhaust stacks. Where air is exhausted in an aesthetic enclosure (sometimes called an architectural screen), the air intake should not be located in the enclosure.

Stacks downwind and higher than intakes

Hood exhaust stacks should be located downwind of intakes, and the discharge point should be 10 feet above the adjacent roof line or air intake if it is within 50 feet. Discharge should be vertical, with exit velocities of 3000 feet per minute or greater.

Put exhaust fans on the roof

Hood exhaust fans should be located on the roof, outside of the building. This maintains a negative pressure within the ductwork, minimizing air leakage and reducing odor complaints.

Ductwork should be properly sized and compatible with contaminants.

Managing Variable Air Volume Systems (VAV)

The state of the art of VAV systems is very good for HVAC comfort systems, and is improving for hood exhaust and makeup air systems.

Many modern HVAC systems, and some lab fume hood exhaust systems are now designed to vary the air flow. The object is to minimize energy consumption and costs. These variable air volume (VAV) systems require sophisticated controls and meticulous maintenance to ensure emission control, meet codes and standards, and keep pressure relationships correct.

Where lab fume hoods are provided with variable exhaust air capabilities, an integrated control system must be provided to also vary the supply air.

Exhaust hood VAV systems reduce the flow rate as the sash is lowered. Good VAV systems will not reduce the air flow until the sash is one-third to one-half closed, and will maintain a minimum flow at all times.

Generally, simplicity is still the rule.

The most simple form of VAV for hoods is a two-speed fan. The normal speed provides adequate exhaust volumes for hood operations. The low speed (typically about 50% of normal) provides control of the hood during non-operational times (e.g., at night time.)

The following precautions should be followed when using VAV systems with lab fume hoods: (13)

VAV systems are expensive to design, build, and maintain. Savings only occur when sophisticated maintenance is provided.

1. VAV systems should not be used on high-activity radio isotope hoods or biosafety cabinets. (These employ HEPA filters and stack samplers which could be adversely effected by VAV systems.)

2. Other exhaust equipment should not be attached to the same hood/duct/fan system.

3. The lab should be maintained at the same pressure relationship with adjacent areas at all times.

4. The lab should maintain at least 6-8 air changes per hour with the VAV system in the minimum position.

5. A monitor should be provided to warn the user should malfunctions occur.

6. An override capability should be provided.

7. The hood should be provided with an air flow monitor.

8. Maintenance must be provided. Maintenance personnel must be trained and equipped.

Where supply and HVAC systems are of the VAV type, a minimum amount of air must always be provided to meet codes and standards, and to provide appropriate air exchange rates and outdoor air supply rates.

Managing chemical storage

Most labs are equipped with a variety of storage facilities (e.g., flammable storage cabinets, compressed gas cylinder cabinets, and so forth.) The following good practices should be followed: (13)

1. Vented gas cylinder cabinets should be designed to provide an exhaust volume of 80 cfm per square foot of storage area, or 200 fpm face velocity through cabinet openings. This exhaust flow rate is designed to control

small leaks and fugitive emissions, not violent ruptures of the cylinders.

2. Chemicals are often stored in a cabinet below the fume hood. These may be vented into the hood exhaust plenum through a 1-2" pipe. (Vented cabinets are optional.)

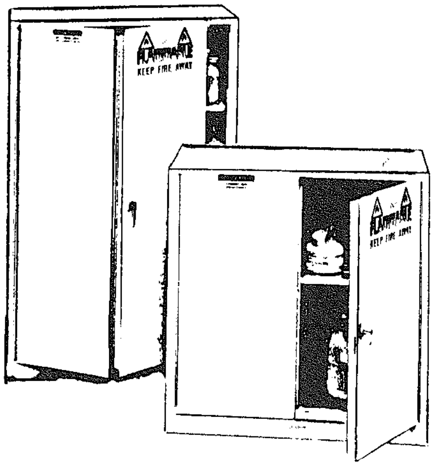
3. Free standing or wall-mounted chemical storage cabinets may be provided with exhaust ventilation. Fifty cfm is a common exhaust volume and is intended to control odors from minor leaks. (Again, vented cabinets are optional.)

4. Ventilation requirements for flammable storage cabinets are established by local fire codes. In general these cabinets are not vented.

Actually, a flammable storage cabinet is designed to protect the chemicals in the cabinet from a fire, not the reverse. However, odors from the cabinet may be controlled by providing a small exhaust ventilation system (e.g., 25 cfm) attached to the upper vent of the cabinet. A hard connected pipe should be attached to the lower vent and extended to a less hazardous area of the lab. This will help protect the stored chemicals in the event of a fire in the lab.

Another approach is to provide an automatic shutoff of the exhaust fan in the event of a fire.

OSHA requires a minimum of six air changes per hour in flammable storage rooms. More information on flammable storage ventilation is provided in NFPA 45 and 30.



Cost management

Geographical location is important. Check out your area.

In labs having a large number of exhaust hoods, the costs can be high for heating and cooling replacement air. Cooling air in summer is typically more costly than heating air in winter. Costs include capital costs of equipment, and operating maintenance costs after installation.

Several approaches are available to reduce costs:

1. Reduce the amount of tempered air exhausted.
2. Reduce the amount of air to be conditioned.
3. Use low cost fuels.
4. Use heat exchangers.

Lets look at each of these options in more detail.

1. Reduce the amount of tempered air exhausted.

It is possible to reduce the amount of tempered air exhausted by any of the following approaches:

Lower the volume flow rate through each hood. This will reduce the face velocity in the hood unless the there is a similar reduction in face area. Remember the formula $Q = VA$. If Q is reduced, and V is to remain constant, then A must be reduced by a similar amount.

Example No. 1. A hood exhausts 1000 cubic feet per minute of standard air. ($Q = 1{,}000$ scfm.) When the hood sash is up (30 inches above the bench), the face velocity in the hood is 100 feet per minute. ($V_f = 100$ fpm.) It is desired to reduce the volume flow rate by 50%. In order to maintain the face velocity, how high can the sash be raised?

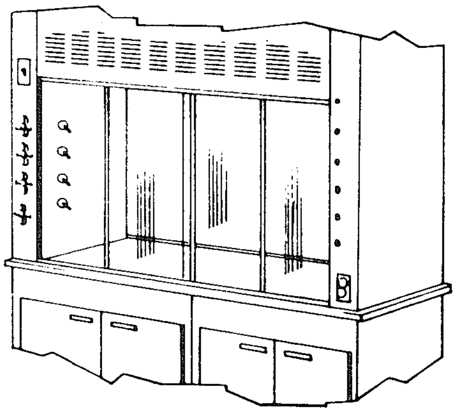
$$\text{If } Q_1 = V_1A_1 \text{ then } Q_2 = 0.5Q_1 = (V_1)(0.5A_1)$$

So the sash must be positioned at the halfway point, 15 inches above the bench surface.

Exercise No. 2. A hood exhausts 1200 cubic feet per minute of standard air. ($Q = 1{,}200$ scfm.) When the hood sash is up (28 inches above the bench), the face velocity in the hood is 110 feet per minute. ($V_f = 110$ fpm.) It is desired to reduce the volume flow rate by 30%. In order to maintain the face velocity, how high can the sash be raised?

The sash must be positioned at 19.6 inches above the bench surface. (This is not a good practice, generally.)

Another approach to reducing the amount of air exhausted is to use horizontal sliding doors in the lab hood (in place of the vertical sash.) There are kits on the market for replacing an existing sash with two or more sliding doors. New hoods can be ordered with horizontal doors.



If a hood sash is replaced with two horizontal doors, the face area is always one-half covered, thereby allowing a reduction of volume flow rate by one-half. Three horizontal sliding doors will reduce the area by at least one-third, with a similar reduction of Q possible.

Horizontal sliding doors offer several advantages and disadvantages. For example, employees can work around a narrow sliding door (up to 14" wide), and have splash/flash protection. On the other hand, horizontal doors can become jammed because the sliding mechanism fails. Horizontal door are sometimes removed by the lab technician, reducing the face velocity.

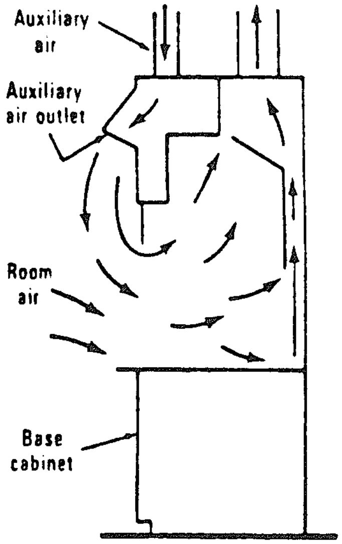
Yet another approach to reducing air flow is to cut back the air exhausted and *actually allow* a reduction in face velocity.

For example, suppose a hood is exhausting Q = 1,200 scfm and the face velocity in the hood is V_f = 140 fpm. If the volume flow rate is reduced to Q = 800 scfm, then the face velocity will be reduced to:

$$V_2 = (800/1200) \times V_1 = 0.667 \times 140 = 93 \text{ fpm.}$$

Is this acceptable? A number of studies have shown that face velocity alone is poor predictor of hood performance, and that there is not a linear relationship between face velocity and fugitive emissions. In fact, it has been suggested that a face velocity of 80 fpm is as effective as 120 fpm, if the hood is in good working order, work practices are good, and there are no cross drafts at the face of the hood. Chapters 5 and 12 discuss these issues in more depth.

Finally, VAV systems can reduce the amount of air exhausted. Most VAV systems are designed to exhaust only that air necessary to maintain minimum face velocities. (See the discussion above.)



2. Reduce the amount of air to be conditioned.

This approach implies bringing replacement air into the lab without conditioning. In this era, it is not acceptable to allow indoor air temperatures and humidities to vary widely, as would occur if outdoor air was not conditioned. However the *auxiliary-air supplied hood* is intended to use up to 70% unconditioned replacement air. The air is ducted to the front of the hood and provides up to 70% of the exhausted air. [Currently, it is not generally recommended that these types of hoods be purchased, installed, built, or used. These hoods are discussed in Chapter 5 in more detail.]

This approach also suggests the possibility of recirculation of exhaust air. Currently, recirculation of lab hood exhaust air is not recommended, and may be prohibited by standards and codes. (See NFPA 45 in Chapter 12, for example.) Laboratory space HVAC air should only be recirculated under the restrictive conditions listed on page 34.

3. *Use low cost fuels.*
4. *Use heat exchangers*

Sometimes it may be possible to use a lower-cost fuel. Heat exchanging has been used with some success. Payback times may be as little as 1-2 years, depending on local conditions. More information can be obtained from your local gas and electric utilities.

Administrative participation—managing lab ventilation systems

Existing codes and standards require active participation by management in providing a lab ventilation program which assures continued performance of ventilation systems. Such management programs usually include:

Management

- Acceptance of responsibility
- Assignment of a cognizant person,
- Record keeping provisions,
- Maintenance of up-to-date plans and specifications,
- Development of emergency plans,
- Employee training,
- Provisions for installing hood testing mechanism, and
- Providing hood-use approval mechanisms.

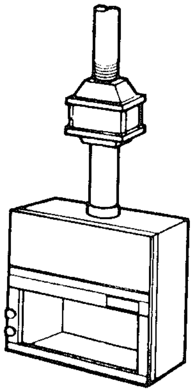
A sample Management Plan is provided in the Appendix. (See Specification No. 2 in the **Charts** section.)

Good Practices

The following management practices are provided as a way of introducing upcoming chapters. They represent a summary of the suggestions found in the sources on laboratory ventilation in the Appendix section **More Information:**

For hoods

The hood itself should not degrade acceptable exhaust ventilation. Hoods are most effective when:



- The proper type of hood for the operation/chemicals is used (e.g., perchloric acid in approved perchloric acid fume hood)
- Air does not leak from the hood
- Hood surfaces are not corroded
- Hood surfaces are not dirty
- Hood mechanisms are all operable and in good condition
- The sash is in proper working order
- Electrical services in hood meet NEC requirements
- Chemical storage is not allowed in the hood
- Other storage is not allowed in the hood
- Equipment is not placed within 6" of hood face
- A real-time airflow monitor is installed (i.e., hood static pressure monitor)
- The hood is made of non-flammable construction materials
- Slots are open to appropriate size
- Slots are not blocked by equipment, chemicals
- No open containers are found in the hood during non-use of the hood

Work practices at hoods

Optimum work practices for maintaining adequate exhaust ventilation include:

- Placing the sash at the proper height.
- Not using the hood when hood exhaust is off
- Using the hood during chemical operations
- Allowing only appropriate chemicals in the hood
- Controlling noise
- Training personnel

- Avoiding rapid movements at hood face
- Not placing upper body in hood
- Limiting use of chemicals outside hood
- Using perchloric acid in approved hoods only
- Working six inches inside the hood

For ductwork

Adequate ventilation cannot be maintained when ductwork is unacceptable. These conditions may exist when:

- Ductwork has holes in it
- Air leaks into or out of the duct
- The duct is dented
- There is poor construction
- The duct is plugged
- There are corroded ducts
- Dampers are improperly set
- There are fire dampers in exhaust system
- Ducts do not meet SMACNA criteria

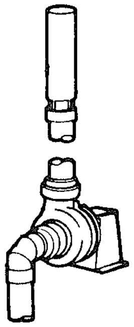
For fans

Correct selection and maintenance of fans and motors are essential. Ventilation will not be adequate when fans:

- Are worn out, or have corroded fan components
- Are turning backward
- Have insufficient rpm
- Have insufficient rated horsepower
- Have belts slipping or broken
- Have motors burned out, or undersized
- Are undersized

For stacks

Ventilation may suffer when stacks are:



- Not attached
- In an inappropriate location (i.e., upwind of air intakes within 50 feet)
- Of inadequate height (i.e., <10 feet above the adjacent air intake if within 50 feet; or <10 feet above the adjacent roof line)
- Provided with insufficient stack exit velocity (i.e., less than 3000 fpm)
- Provided with esthetics enclosures which hinder dispersion

For exhaust volumes

Lab fume hood exhaust ventilation is generally acceptable when:

- Adequate exhaust volume is provided (i.e., sufficient to maintain containment and appropriate face velocities with sash in **up** position)
- Adequate face velocity is provided (e.g., greater than 80 fpm average with sash in the **up** position)
- Adequate face velocity range exists (i.e., less than plus or minus 25% of average face velocity)
- Turbulence in hood face does not exist (e.g., any single face velocity reading varies not more than plus or minus 25% of the average; or turbulent air movement is below 40-50 fpm at the face with the hood exhaust off.)

For replacement air

Replacement ventilation is generally adequate when:

- Replacement air is supplied by mechanical systems
- Replacement air is sufficient for dilution of fugitive emissions
- Replacement air is not contaminated by exhaust air,
- The supply diffuser does not blow on the hood face
- The supply diffuser is not blocked
- Temperatures are adequate
- Employees do not complain of noise, drafts
- Replacement air meets ASHRAE 62 provisions
- The supply is balanced with exhaust

Ventilation effectiveness will be maintained when:

- Adequate maintenance keeps equipment repaired
- An ongoing PM program is provided

For storage

Ventilation is usually more effective when appropriate chemical storage is provided. Good practices:

- Cabinets are not missing doors or panels
- Cabinets are constructed of nonflammable materials
- Cabinets avoid mixed acids/solvents/bases
- Electrical outlets in cabinet meet NEC code

- The cabinet is an approved fire-rated cabinet
- The cabinet is non-corroded
- The cabinet is clean
- There are no open containers
- There are no unlabeled containers
- A fire extinguisher is provided

Ventilation may be adversely effected when:

- The lab is cluttered, dirty; housekeeping poor
- Hood is positioned near door, window, walkway
- Fire escape routes are blocked
- Aisles are blocked

Several hoods manifolded together on one fan may present problems for the ventilation when:

- Incompatible chemicals mix in the air
- Corrosion occurs in the manifold
- Condensation occurs in the manifold
- One hood goes positive (allowing air from other hoods to enter the lab through it)
- Part of system comes under positive pressure (allowing contaminated air to leak from the duct into the lab)

Exercise 3. Please find extra Checklist No. 3, *Checklist for Safety and Housekeeping*. This checklist can be used as an aid during the analysis of a lab for "good practices" as they relate to safety and housekeeping. Using the Checklist, inspect a laboratory. Where a lab is not available, evaluate from memory a lab you are familiar with.

Case Study

Lab smells cause complaints

The call for help came on Tuesday morning. Ted responded on Wednesday morning. It was solved by Wednesday afternoon.

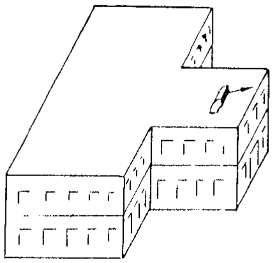
“It took a surprisingly short time to dispose of this one," Ted said. "Especially when you consider that the problem had been going on for almost three years.”

The local veterans hospital had filled three file drawers with the paper work generated by the case. It all started when several clerical workers in the front office noticed some objectionable odors. A memo had been written asking for an investigation. At the time, nothing had been done. Complaints continued, however.

About three months later, several of the clerks had left work, sick from the “fumes” that they felt were being recirculated into the building from the Pathology Lab. A formal complaint was filed, the union was called in, and lawyers contacted.

“It was those lawyer's involvement that got the attention of management,” Ted chuckled. “Over the next three years, seven separate studies were conducted. First by the in-house environmental people, then by the Washington staff, then by an outside industrial hygiene consulting firm, then by an A&E, plus several more. No one could agree on the exact cause or solution.”

During the first morning, Ted collected the following information:



- Clerical employees in the south wing of the second floor were complaining of chemical smells in their offices. The first complaints had come about three years ago, and had continued unabated to the present time.
- Industrial hygiene studies had not found any concentrations of airborne chemicals exceeding one-tenth recognized standards. Indeed, airborne concentrations

rarely exceeded the limits of detection of the testing methods.

- Medical exams had been conducted, but there had been no clinical diagnosis of illness among clerical workers.
- A pathology lab was located in the west wing of the second floor.
- Pathology lab fume hoods were exhausted through a common discharge located on the roof. The discharge was horizontal, about three feet above the roof surface.

Exercise No. 4. From the data given so far, what comes to mind as a potential source of the trouble?

Additional data:

- One environmental study reported that exhaust air from the discharge routinely blew across the roof and down the north wall, infiltrating the offices along the north wall.
- One engineering study had recommended a thirty foot stack to replace the existing horizontal discharge. This modification would also require replacing existing duct work and fans, and modifying the structural supports on the roof. The estimated cost was $125,000.
- A request for the money had been sent to the Washington office, but had not survived this year's budget cuts.
- Clerical employees were threatening a work action and a law suit had been filed with local federal court.

"I immediately recognized that the Pathology lab was the source of the smells," Ted said. "You never forget those odors—they're very distinctive. But I was suspicious of the infiltration theory."

Ted had taken his smoke tubes to the clerical offices in the north wing. An older building, the windows could be opened. Ted cracked the window at several points and noted that there was a definite airflow out the window. The clerical offices were under positive pressure with respect to the outside air. This was typical, and the appropriate condition for large office buildings.

"The building was built to be under a slight positive pressure. That makes control of the indoor environment a little easier," Ted said. "I also noted that there was considerable amount of air entering the offices from the hallway. The hallway was under positive pressure with regards to the offices. The building engineer and I talked at some length. It seems that balancing had been a problem in the building over the years. Plus, there had been a lot of changes. That is normal for labs and hospitals."

Ted checked the Pathology Lab ventilation as well. It was typical of chemical labs. There were six lab fume hoods, each exhausting about 1200 cubic feet of air per minute. Three of the hoods were auxiliary-air supplied, and smoke containment tests suggested a small amount of fugitive emissions from these three hoods. Chemicals used in the hoods, although odorous, were not particularly toxic, however, and the lab technicians were not upset over existing conditions.

"A replacement air system served the lab, but had been added only about three years ago, almost at the same time complaints began." Ted reported.

Exercise No. 5. From the additional information given, what now comes to mind as a potential source of the trouble?

Ted continued his story. "It was too coincidental--complaints began about the same time as the modification to the lab replacement air system," Ted said. "June taught me long ago that when you hear hoofbeats, think of horses, not zebras. This seemed almost too obvious."

Ted continued the story. "I checked the airflow at the doors to the lab. Air was flowing from the lab into the hallway. The lab was under positive pressure with respect to the hallway. As you know, we try to keep labs negative with respect to adjacent spaces. Once in the hallway, the air drifted down the hall and into the north wing, where it then infiltrated the offices. I checked it with smoke tubes."

"I asked for and looked at the modification specifications for the new replacement air system installed three years ago." Ted's face suggested a look of pleasant amazement. Such specifications are often lost or not available. "The design engineer had sized the replacement air system for six hoods, not three. When the auxiliary-air hoods were on, the room was over-supplied with replacement air. That put the room under positive pressure, of course."

Ted held a quick meeting with the hospital administrator and got her approval to try some modifications that very afternoon. With permission, he and the building engineer shut down the air supply to the auxiliary-air hoods. The exhaust fans for the hoods were left on. "The room immediately went slightly negative. And the fugitive emissions from the auxiliary-air hoods ceased. We killed two birds with one stone," Ted laughed, pleased with the outcome.

A meeting was quickly called with the administrative staff of the clerical department.

Exercise No. 6. What would you say to the clerical staff?

Ted continued the story. "I told the clerical staff of our findings. I told them we thought we had identified the problem and solved it. And I reassured them that even though they had smelled chemical smells, their exposure levels had been very low. In fact, Pathology Lab technicians had been exposed to higher concentrations, and none of them had ever registered a complaint, and nobody in the building was at any particular risk.

"One of the clerical staff was skeptical, and said he could smell chemicals right then, right there in the conference room. And it was true. The supervisor of the Pathology Lab was in the meeting, and her lab coat had some chemicals spilled on it. We could smell those chemicals on her lab coat, if we thought about it. I suggested that perhaps they might be experiencing a little bit of over-sensitivity, given the past three year's experience. I asked for their cooperation in giving our solution a try. They agreed. That ended the discussion."

Ted closed the file and placed it in the cabinet. "I spoke with the manager of the clerical department last week. It's been three months since the modification, and no one in the department has complained. Case closed!"

Answers to Exercises

Exercise No. 1. A good exercise, but time consuming.

Exercise No. 2. A hood exhausts 1200 cubic feet per minute of standard air. ($Q = 1{,}200$ scfm.) When the hood sash is up (28 inches above the bench), the face velocity in the hood is 110 feet per minute. ($V_f = 110$ fpm.) It is desired to reduce the volume flow rate by 30%. In order to maintain the face velocity, how high can the sash be raised?

If $Q_1 = V_1A_1$ then $Q_2 = 0.7Q_1 = (V_1)(0.7A_1)$

Since A = w x h, and width w remains constant, then

$$h_2 = 0.7\ h_1 = (0.7)(28") = 19.6"$$

So the sash must be positioned at 19.6 inches above the bench surface in order to maintain a face velocity of V = 110 fpm.

Exercise No. 3. Use of checklists enhances clarity and completeness (i.e., it helps us remember to do it right.)

Exercise No. 4. From the data given so far, what comes to mind as a potential source of the trouble?

Almost anything could be happening, but it seems possible that exhaust air is being reentrained into the building air handling system.

Exercise No. 5. From the additional information given, what now comes to mind as a potential source of the trouble?

We now know a potential source of the chemicals--fugitive emissions from the hoods. The replacement air system modification may be involved in some way.

Exercise No. 6. What would you say to the clerical staff?

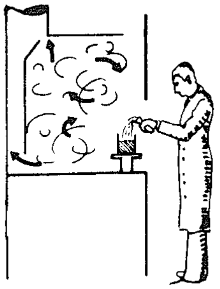
Check out Ted's approach.

Chapter 5.
Chemical Laboratory Fume Hoods

General considerations

Objectives

The objective of any hood is to control emissions (and resulting exposures). A lab fume hood controls an emission by enclosing and containing the emission within the hood.

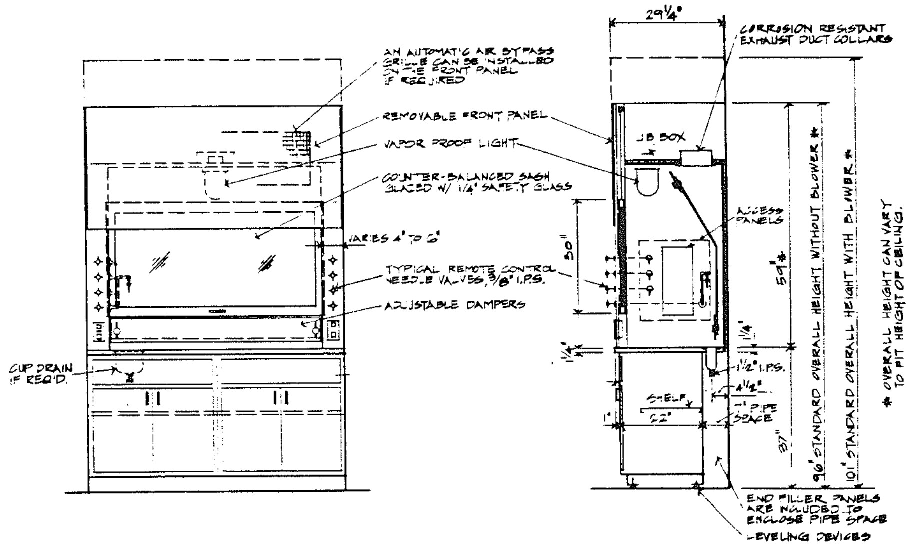


Containment and removal

Laboratory operations involving toxic, hazardous, or odoriferous materials are usually conducted within an enclosure hood. Air flow into the hood mixes with emitted contaminants and the air carries them into the exhaust duct. Successful containment minimizes fugitive emissions from the hood. This protects the lab worker standing in front of the hood and keeps background levels of contaminants in the lab at acceptable concentrations.

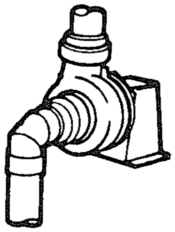
The American Chemical Society (among others) has suggested that where workers spend much of their time working with chemicals, at least one hood should be provided for each two workers. Each worker should have at least 2.5 linear feet of working space at the hood face. (33)

This chapter presents good practices in the selection and operation of lab fume hoods.


AN AUTOMATIC AIR BYPASS GRILLE CAN BE INSTALLED ON THE FRONT PANEL IF REQUIRED
REMOVABLE FRONT PANEL
VAPOR PROOF LIGHT
COUNTER-BALANCED SASH GLAZED W/ 1/4" SAFETY GLASS
VARIES 4" TO 6"
TYPICAL REMOTE CONTROL NEEDLE VALVES, 3/8" I.P.S.
ADJUSTABLE DAMPERS
CUP DRAIN IF REQ'D.
29 1/4"
CORROSION RESISTANT EXHAUST DUCT COLLARS
JB BOX
ACCESS PANELS
30"
59"*
1 1/4"
1 1/4"
1 1/2" I.P.S.
4 1/2"
PIPE SPACE
SHELF
22"
1"
37"
96" STANDARD OVERALL HEIGHT WITHOUT BLOWER *
101" STANDARD OVERALL HEIGHT WITH BLOWER *
* OVERALL HEIGHT CAN VARY TO FIT HEIGHT OF CEILING.
END FILLER PANELS ARE INCLUDED TO ENCLOSE PIPE SPACE
LEVELING DEVICES

Have you read Chapters 3 and 4? It would be best to do so before proceeding.

Static pressure



In a lab fume hood exhaust system, the fan creates negative static pressure in the duct serving the hood. Atmospheric pressure pushes air into the hood (and then into the duct) in an effort to equalize the pressure. But the fan continues to turn. Within a few seconds of turning on the fan, a steady state condition of flow is established.

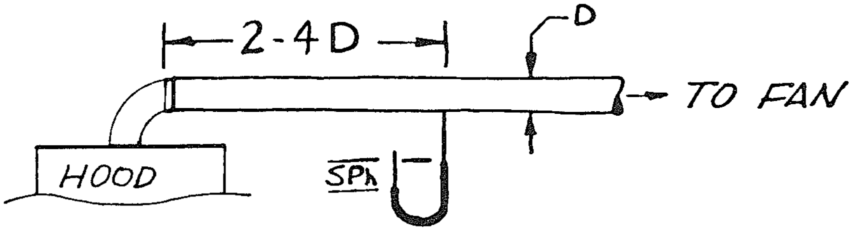
At the lab hood, all of the static pressure in the duct is converted to *velocity pressure* or to *hood entry loss*. In other words, the static pressure in the duct near the hood, called the "hood static pressure," SPh, is converted either to VP, or to the entry losses, He. This is described algebraically by

$$|\mathbf{SPh}| = \mathbf{VP} + \mathbf{He}$$

where

$|SPh|$ = the absolute value of the static pressure in the duct serving the lab hood, inches w.g. (mm w.g.)
VP = duct velocity pressure, inch wg (mm w.g.)
He = hood entry loss, inch wg (mm w.g.)

Hood static pressure should be measured in the duct serving the hood, usually about 4-5 duct diameters downstream from the hood. If an elbow occurs before a straight section is obtained, take the measurement downstream. (The elbow loss becomes part of the hood loss.) Mark your hole for future use.

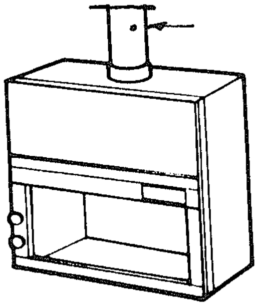


Example 1. What is the hood static pressure when the duct velocity is 0.33 inches w.g., and the hood entry loss is 0.43 inches w.g.?

$$\mathbf{SPh} = \mathbf{VP} + \mathbf{He}$$

$$= 0.33 + 0.44 = 0.77 \text{ inch w.g.}$$

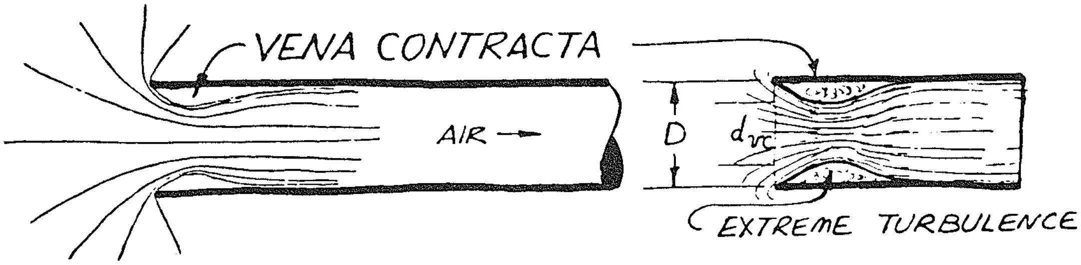
(The static pressure is SP = -0.77 inches w.g.)



Exercise 1. What is the hood static pressure when the duct velocity is 0.25 inches w.g., and the hood entry loss is 0.50 inches w.g.

Vena contract

Hood entry losses normally occur at the hood slots and at the entrance to the duct, due to the vena contracta formed. The next figure illustrates a vena contracta. The most narrowed portion of the vena contracta is usually found about one-half duct diameter (or one half of the slot width) inside the duct (or plenum.)



Entry losses

The hood entry loss, He, is the sum total of all the losses from the hood face to the point of measurement in the duct. Again, in a lab fume hood, this means the loss at the slots and the loss as the air enters the duct.

Most ventilation system losses can be expressed in the format

$$\mathbf{SP\ (loss) = K \bullet VP_{duct}}$$

Therefore, $\mathbf{He = K \bullet VP_{duct}}$,

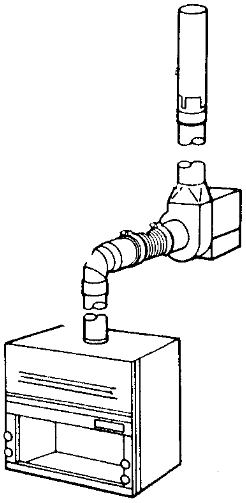
where **K** is the "hood entry loss factor."

Hood entry loss factors (**K**) have been estimated over the years and have been reported in the literature for many types of hoods, including lab fume hoods. [See the *Industrial Ventilation Workbook* or the *Industrial Ventilation Manual,* Reference No.s 3 and 4.]

For example, a *simple bypass lab fume hood* has an approximate hood entry loss of:

$$\mathbf{He = K \bullet VP_{duct} \approx 2VP_{duct}}$$

where K = 2.0, from the literature.

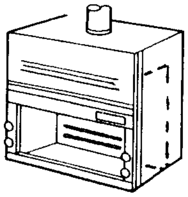


Example 2. What is the entry loss, He, for a laboratory fume hood when the average velocity pressure in the duct is VPd = 0.30" w.g.? (Assume K = 2.0)

$He = K \bullet VPd = 2.0 \times 0.30 = 0.60$" w.g.

Exercise 2. What is the entry loss He for a lab fume hood when the average velocity pressure in the duct is VPd = 0.38" w.g.? The hood loss factor is K = 1.88 (from the hood manufacturer).

Compound hood

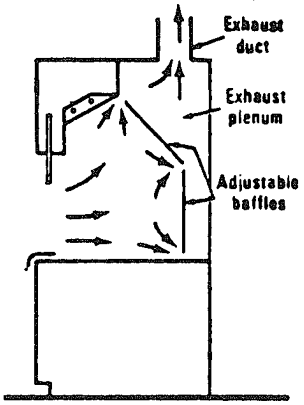


Lab fume hoods almost always have slots and a plenum. A slotted hood is a compound hood—it requires air to "enter" twice—first through the slot into a plenum, where velocity is reduced, and then from the plenum into a duct. Slotted hood entry loss factors are also compound (that is, there are two losses):

$$\mathbf{He = Ks \bullet VP(slot) + Kd \bullet VP(duct)}$$

Slot loss

The loss associated with a slot is similar to the loss associated with a sharp-edged orifice. The value $K_s = 1.78$ is almost always used.



A uniform velocity across the hood face requires a uniform static pressure across the slots.

Slots do not reach out to capture contaminants. The plenum-slot arrangement distributes plenum static pressure evenly across the back of the slots so that air flow into the hood is equalized across the face of the hood.

Finally, what is the predicted hood static pressure for a compound, slotted hood? As we saw above,

$$\mathbf{|\,SPh\,| = VP + He}$$

so, for a slotted hood

$$\mathbf{|\,SPh\,| = VPs + VPd + Ks \bullet VPs + Kd \bullet VPd}$$

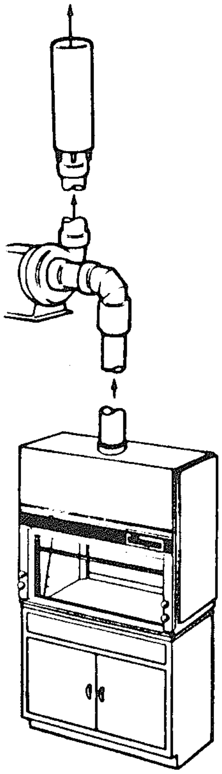
= accelerations + losses

where
VPs = velocity pressure in slot
VPd = velocity pressure in duct

Ks = entry loss factor for slots, K = 1.78
VPs = Velocity pressure in slot
Kd = entry loss factor for the duct entry. (Usually K = 0.25 for tapered duct takeoffs, K = 0.5 for straight takeoffs.)

So,

$$|SPh| = 2.78VPs + (1+K)VPd$$



for most cases. (Occasionally, the acceleration achieved in the slot can be carried on into the duct, but this occurs only rarely, e.g., when a carefully designed duct takeoff lies directly behind the slot. Mostly, the acceleration of the slot is lost in the plenum. Using the above equation errs on the side of safety, but not by much.)

Example 3. Determine the SPh required for a lab fume hood where the duct velocity is Vd = 2,000 fpm, and the slot velocity is VPs = 1,300 fpm; let Kd = 0.5 (a straight takeoff at the duct entrance.)

$$SPh = 2.78VPs + (1+K)VPd$$

from Chart No. 5, VPs = 0.11" w.g.
and VPd = 0.25" w.g.

$$SPh = 2.78(0.11) + (1+0.5)(0.25)$$
$$= 0.68\text{" w.g. (absolute value of static pressure)}$$

These two exercises show typical static pressures found at lab fume hoods.

Exercise 3. Determine the SPh required for a lab fume hood where the duct velocity is Vd = 2,400 fpm, and the slot velocity is VPs = 1,500 fpm; let Kd = 0.25 (a tapered takeoff at the duct entrance.)
(Use SPh = 2.78VPs + (1+K)VPd)

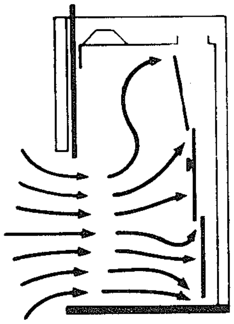
Face velocities and volume flow rates

Generally acceptable laboratory fume hood face velocities range from 60-150 fpm.

Current and past recommendations include:

A wide range of face velocities are generally acceptable if work practices and conditions outside the hood are good (e.g.,no competing air currents from fans, and so forth.)

Organization	Recommended Face Velocity, fpm
ANSI	80 -120 (Z9.5, 1992)
ACGIH	60 -100
NIOSH	100 -150
OSHA	150 (for carcinogens)
NFPA	"Sufficient to prevent escape of contaminants from hood"
NRC Reg. Guide 8.23	100 for radioactive materials at medical facilities
NRC Reg. Guide 8.24	150 for enriched uranium-235
CALOSHA	100 minimum



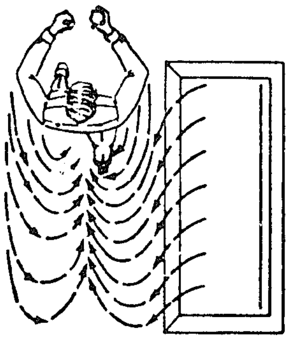
Plan for 100 fpm plus good conditions and good work practices

Many hoods are installed to provide about 100 feet per minute (just over 1 mph) at the face of the hood. This velocity will control most low-velocity cross drafts and the turbulence created by an occasional poor work practice at the face of hood.

What is 100 fpm? Blow lightly on your hand so that you can just barely feel air movement—that's about 100 fpm.

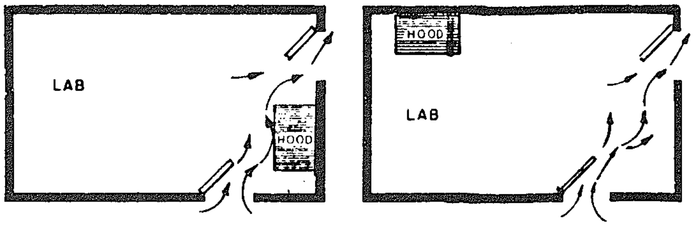
Avoid drafts and air competitors

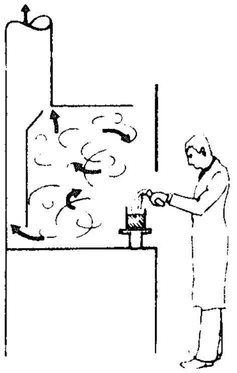
Normal, transient, chaotic, turbulent mixing velocities in general laboratory air may be as high as 50 fpm, even under "good" conditions. You can see that it won't take much of a competing velocity to destroy the hood's



ability to contain emissions. The following is a list of some of the competitors:

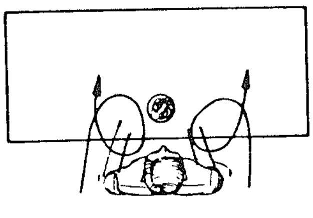
- Make-up and general HVAC room-air ventilation system air supply registers.
- Wind blowing through open windows and doors.
- People walking by (a person walks 200-300 fpm).
- Mobile equipment passing by.
- Obstructions in the path of capture which create eddying, turbulence.



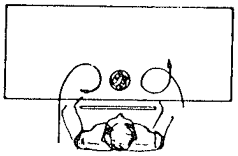


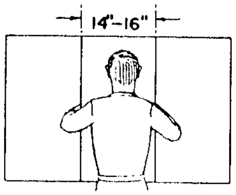
In addition to external air movement, the hood often must compete with employee work practices. You've probably seen cases where a lab employee works in such a way that the hood is not effective in protecting the employee (e.g., the employee stands with his/her head inside the hood, or the employee makes rapid motions with his/her hands and arms inside the hood.)

Chapter 4 provided a list of good work practices which will optimize hood performance.



A face velocity upper limit (traditionally, 150 fpm) has been suggested. As air flows into the hood, eddying around the hood worker's body tends to create a negative pressure area directly in front of the person's body. Any rapid movement of the person's arms may draw contaminated air into that space (which, drat, is also the person's breathing zone.) The eddying effect becomes more pronounced as the face velocity increases. The limit of 150 fpm is a compromise between the eddying effect and the need to provide containment against competing drafts. The eddying effect can also be minimized by the use of horizontal sliding doors. A door about 14 inches wide provides both access and splash protection.





In a study conducted at Los Alamos National Laboratory (which confirmed a number of other studies), face velocities were not shown to be a significant factor in containment. Under the *ideal* test conditions, 60 fpm was as effective as 150 fpm. (26)

Because we cannot create ideal conditions is most labs, a face velocity of 100 fpm, coupled with rigorous control of competing cross-drafts, seems like a sensible face velocity for most operations.

Performance measures, Protection Factors

Quantitative measures

How effective is a hood? How do you measure the performance of a hood? There is no one universally accepted technique for measuring a hood's performance. Important tests published by EPA and others are described below [and in Chapters 10 and 12.]

The most complete testing protocol, the ASHRAE 110 standard (currently the only approved method of testing), compares the ratio of a tracer gas emission rate to the breathing zone (BZ) exposure concentration of a manikin standing in front of the hood:

ASHRAE 110 was in the process of public review and revision as of November, 1993. Proposed new provisions include a VAV testing protocol and two less intensive levels of testing. The new provisions will make the standard more attractive to a larger number of hood users.

Emission rate of tracer gas, lpm

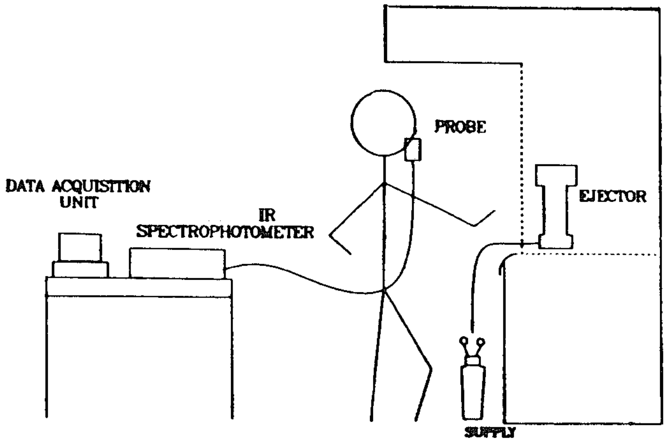
compared to

Concentration of tracer gas in manikin BZ, ppm

To illustrate, if the emission rate of a tracer gas in a hood is 4 liters per minute and the exposure level is

If the test were performed in the users lab, the result would be reported as **4AU0.01**, where AU refers to "As Used." **4AM0.01** indicates "As Manufactured."

C_{bz} = 0.01 ppm, then the comparison between **4** and **0.01** is a measure of the hood's performance. Of the testing methods published, this one is preferred. But it can be time consuming and expensive to conduct. The revised standard will likely include two new, more simple test procedures. See Chapters 10 and 12 for more discussion of the ASHRAE standard test method.



Protection factors

Another useful measure is to estimate the ratio of the concentration of a contaminate in the exhaust air vs. the concentration in the breathing zone of a person working or standing in front of the hood.

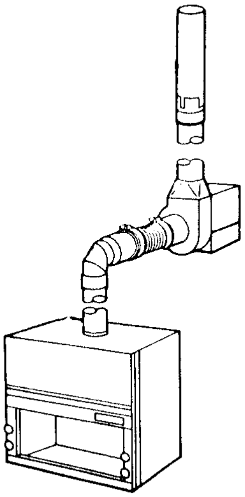
This testing approach monitors the performance of the hood as it is actually used by the lab technician.

$$\textbf{Ratio} = \frac{C_{\textbf{exhaust air}}}{C_{\textbf{breathing zone}}} = \textbf{Protection Factor (PF)}$$

Suppose a person is using methyl alcohol in the hood. If the concentration in the exhaust air is C_{ea} = 100 ppm, and the concentration in the breathing zone is C_{bz} = 0.01 ppm, then the Protection Factor is calculated as follows:

PF = 100/.01 = 10,000.

This approach is quite useful, and is easy to measure or predict. More information on the calculation procedures is found in Chapter 16.



Example 4. Suppose the solvent trichloroethylene (TCE) is being used in a lab fume hood. The solvent use rate is known and is used to estimate the average concentration in the exhaust, $C_{ea} = 50$ ppm. (See Chapter 16 for calculation procedures.) Charcoal (or indicator tube) sampling of the lab worker's breathing zone suggests an average exposure concentration of $C_{bz} = 1$ ppm. What is the hood's Protection Factor?

$PF = C_{ea} / C_{bz}$

$= 50 \text{ ppm} / 1 \text{ ppm} = 50$

Exercise 4. Suppose a solvent (methyl alcohol) is being used in a lab fume hood. The solvent use rate is known, and from that, the concentration in the exhaust air is calculated to average $C_{ea} = 50$ ppm. (See Chapter 16 for calculation procedures.) Charcoal sampling of the lab worker's breathing zone suggests concentrations of C_{bz} less than 0.01 ppm, the limits of detection. What is the minimum hood Protection Factor?

This last exercise suggests protection factors can be quite high. For standard hoods, using relatively non-hazardous materials and typical use rates, protection factors of 300 are easily attainable, and may be adequate for low toxicity chemicals. For standard hoods using more toxic materials, protection factors in excess of 3,000 may be required. For carcinogenic and high-activity radioactive materials, protection factors of 10,000 and more are not uncommon.

These exercises suggest a fact which must be acknowledged:

No hood provides perfect containment of materials emitted within the hood

People will be exposed

It is always possible to improve hood performance, but perfection is not possible. Therefore, people working in laboratories *will be* exposed to materials they handle and use. Our job is to minimize that exposure, given constraints of technical and financial feasibility.

Over the years, other measures of performance and protection have been suggested. One approach was to measure the concentration in the exhaust duct and compare it to background concentrations in the room air. Another suggested measuring the concentration of a contaminant in the hood itself, and comparing that to concentrations just outside the hood. None have proved popular.

Subjective measures

Most lab fume hood users rely on more simple, subjective measures of performance (e.g., face velocities, face velocity ranges, smoke containment, lack of employee complaints, adherence to recognized standards, and so forth.) These testing methods are covered in detail in Chapter 10.

(Optional) Exercise 5. If you have access to a laboratory fume hood system, examine several hoods.

1. Are the hoods intact and operating properly?

2. Evaluate the potential for competing cross drafts and turbulence at each of the hood faces. Are there fans, air supply registers, open windows, walkways, or other draft-producers present?

3. Evaluate work practices. Does the lab technician work well in the hood? Or does the technician interfere with the purpose of the hood?

4. Does the hood actually do its job—containing and removing emitted contaminants? Why or why not? What kind of performance or protection does the hood appear to provide?

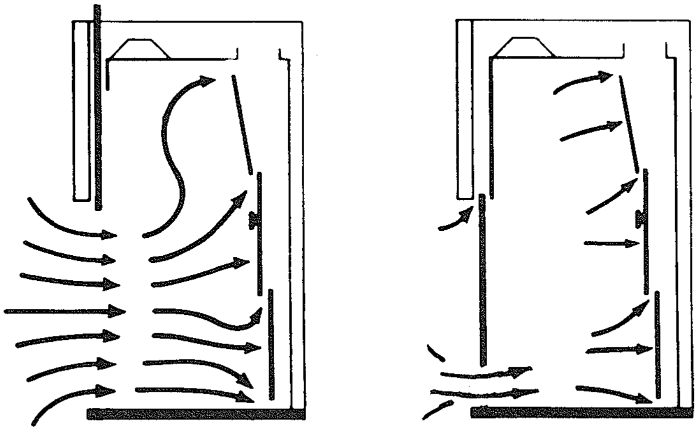
Types of Laboratory Fume Hoods

There are three basic types of lab fume hoods (and many specialty hoods, some of which are covered in the next three Chapters.) The three basic types are:

- The conventional (including VAV) fume hood.
- The bypass and/or constant-volume hood.
- The auxiliary air supplied hood.

Conventional (or standard) hood

A standard, non-VAV fume hood is shown below. It is simply a box with a sash, baffles, slots, a plenum, and a take-off duct. Air flows through the front opening and exhausts through the plenum and the duct.



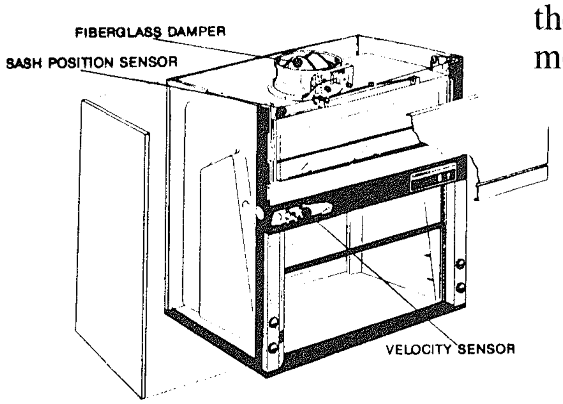
If the sash is closed, the face velocity increases. At about 1/4th open, the face velocity will increase to about 400-500 fpm in a typical hood. As the sash closes completely, the face velocity will increase non-linearly to 1000-2000 fpm, and the flow rate will decrease. At the fully closed position, very little flow may occur, just that which can leak in around the sash, the airfoil sill, and so forth.

The conventional hood is typically less expensive than other types. But it has the drawback of increasing face velocities as the sash closes. This may blow papers around, or bottles over. If the sash is totally closed, vapors may build in the hood to explosive concentrations. Additionally, the air balance in the lab will be altered unless the supply air also decreases.

Conventional VAV hood

Conventional hoods can be fitted with a device which varies the flow as the sash closes. Called the *Conventional VAV hood,* it usually uses a damper in the duct to reduce the flow. Several types are available:

- Mechanical feedback systems use a chain attached to the sash which varies the damper in the exhaust duct. As the sash closes, the chain closes the damper proportionately.
- Pneumatic feedback systems sense the pressure change in the hood as the sash closes. A pneumatic device closes the damper, or a transducer varies the speed of the fan motor.
- Electric feedback systems sense the position of the door electronically. An electrical signal (1) may be sent to a damper motor which varies the position of the damper, or (2) may vary the fan speed with a motor speed controller.



Pros

The major advantage of the VAV hood is energy (and cost) conservation. As the sash is lowered, less tempered air is exhausted to the outside atmosphere. This can result in considerable savings. (See more discussion in Chapter 4.)

and

The VAV hood also minimizes the problem of constantly varying face velocities as the sash position changes.

Cons

VAV hoods can create the problem of zero air flow when the sash is fully closed.

If the air supply system is not integrated into the VAV control scheme, the room will be unbalanced as the hood exhaust rate varies.

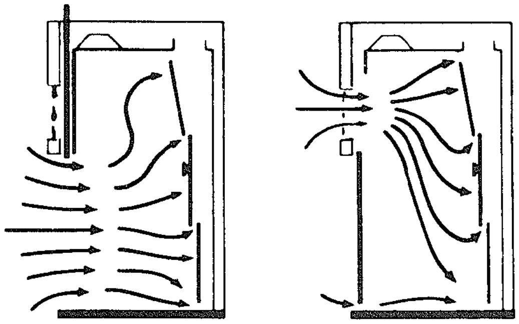
VAV equipment response times may not allow the hood exhaust system to keep pace with the sash. This creates conditions where the air flow through the hood may fall below acceptable minimums.

Reliability of VAV equipment has traditionally been a problem, often requiring heroic maintenance efforts.

Before using VAV hoods, you should weigh whether or not the added expenses, increased risks of equipment failure, and greater maintenance efforts are worth the "energy conservation" to be achieved.

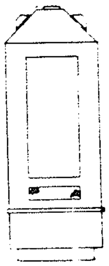
Bypass hood
(also known as the
constant volume hood)

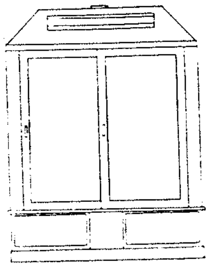
The bypass hood has features which attempt to avoid the problems of the conventional hood. It provides a path for air to enter the hood (or the duct) regardless of the position of the sash. This maintains a constant volume of exhaust air. The bypass hood solves the problems of balancing and assuring air flow through the hood at all times.

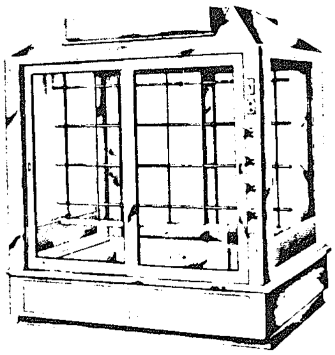


California hood

Variations of these hoods include the California hood, developed at Los Alamos, and the walk-in hood, which allows for the construction of tall chemical apparatus.

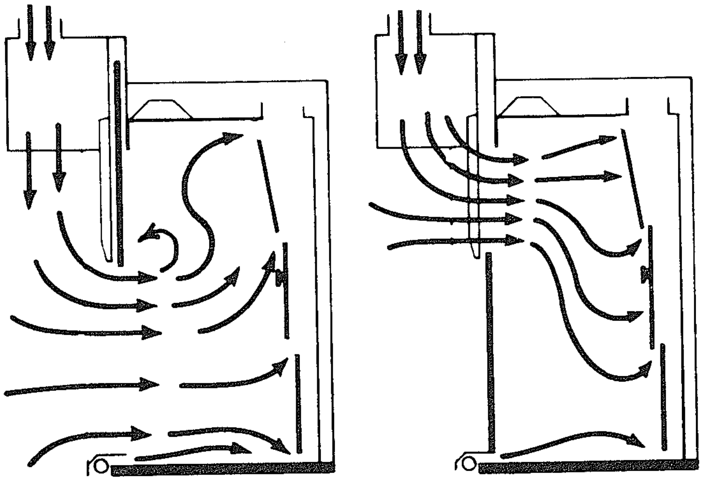






Auxiliary-air hood

The auxiliary-air supplied hood was also developed to reduce energy consumption. Like the Conventional VAV hood, it reduces the amount of tempered air exhausted through the hood. Up to 70% of the exhausted air is supplied to the hood without tempering or conditioning. The air may come from outdoors, utility chases, mechanical rooms, attics, or other non-tempered air locations.



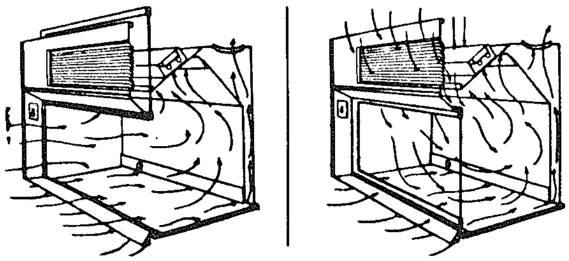
Unfortunately, there are a number of drawbacks to the use of auxiliary-air hoods:

Most modern labs avoid the use of auxiliary-air supplied hoods for these reasons.

- Lab workers must often stand in the supply air stream. This results in dissatisfaction and attempts to defeat the system (e.g., cardboard baffles on the incoming air). During the winter, supply air must be heated to at least 60° F, defeating the winter savings. During the summer, cooling of supply air is not usually required. Depending on the climate, this may result in considerable savings (if employees cooperate.)
- Turbulence in the face of the hood is increased. Eddying and swirling motions around the sash will invariably reduce the hood's containment performance. (Protection Factors are often less than PF = 300.)
- There is no effective way to measure the face velocity of the hood without first shutting down the auxiliary air supply.
- The initial costs are higher. (Multiple ducts, fans, and controls.)
- Imbalance of air supply vs. exhaust can actually sweep air from the hood and into the lab.
- Because of the increased risks and reduced performance, auxiliary-supplied hoods can only be used with relatively less-hazardous materials.
- Untempered air may be lost to the room, upsetting existing heating and cooling systems.

Hood Selection Criteria

Okay, which type of hood should you choose?



There are no easy answers. The following selection criteria should help in the decision-making process.

It is logical that the more toxic the material, the more rigorous the control (e.g., lower face velocity range, and so forth). In fact, for special materials (biohazards, carcinogens) there are specialized hoods which offer extraordinary protection. See Chapters 6-9.

For general chemical labs, numerous attempts have been made to "classify" chemical compounds according to toxicity, evaporation rates, fire properties, and so forth. Unfortunately, none of these classification schemes has proven to be very useful.

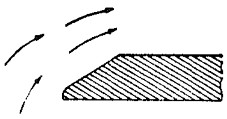
General criteria

Therefore, when selecting a hood consider the following general criteria:

Small but adequate for the task

- **Size, shape and utilities.** For safety and economic operation, the smallest hood should be chosen which will accommodate the operation. The hood should be deep enough to accommodate the operation so that nothing is within six inches of the inside face of the hood. Nothing should be protruding through the face of the hood.

Beveled edges



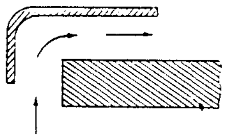
The jamb of the hood should be smooth and beveled. A 45-degree taper is often used. (Reasoning—the taper, sometimes called a "picture-frame edge," reduces eddying at the edge of the hood and improves containment.)

Sash inside the hood

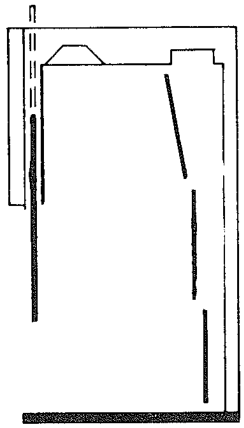
The sash track should be located a few inches inside the front edge of the hood. (Reasoning—this will push the location of the face a little farther back into the hood, improving containment performance.)

Airfoils can also be used on the sash to offset the swirl often found just inside the sash.

The bench (or sill) should be equipped with an airfoil to direct incoming air along the bench surface at all times. This will contain within the hood any heavy vapors which form when liquids are spilled. (Reasoning—the percent concentrations of heavy vapor can "flow" to the front of the hood and wash over the bench edge, creating fugitive emissions.)



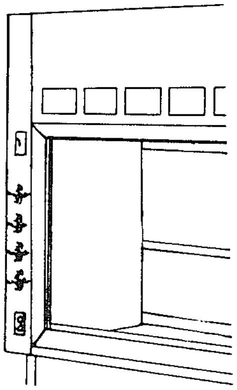
The bench should be equipped with a recess at about six inches inside the hood face. Alternately, the sill should taper to the six inch point. This will remind chemists not to place anything within the first six inches of the hood. (Reasoning—equipment located within six inches of the face reduces velocities at the location, creates eddying and turbulence, and reduces hood containment performance. The recess also helps spilled liquids from migrating to the front of the hood.)



The hood should be equipped with at least three horizontal slots at the back of the hood (one at the bottom, one in the middle, and one at the top). There should always be a slot at the top of the hood, especially if hot processes are in the hood. (Reasoning—the more slots, the better the air distribution and the more consistent the face velocity. The top slot, if missing, may allow warm air to escape at the top front edge of the hood.)

Baffles should be fixed, or not easily adjusted. (Reasoning—this will assure that all slots are open and not easily closed.)

In most cases, slots and baffles should be at the manufacturer's recommended positions. (Reasoning—this will assure maximum air flow and optimum distribution.)



Utilities such as air, gas, and water should be located near the front of the hood. (Reasoning—this keeps lab workers from leaning too far into the hood.)

Controls, switches, handles, and so forth should be located outside the hood enclosure. (Reasoning—this provides fire protection, user protection.)

- **Materials of Construction.** Hoods consist of a body, a sash, and coatings.

Sash

The sash should be made of "shatterproof" material.

Hood

Hood materials should be compatible with the chemicals used. Reference Nos. 14 and 22 (see **More Information** in the Appendix) suggest the following materials and their limitations (listed in decreasing order of cost).

Hood Material	Limitations
• Epoxy	Versatile
• Stainless steel	Attacked by HCl
• Monel metal	Check chemical compatibility
• Steel w/ coatings	Check chemical compatibility
• Aluminum	Use only for light service; attacked by alkaline
• FRP and other plastics	Use only for light service; check local fire codes; check chemical compatibility
• Wood	Avoid use; check fire codes

Glass

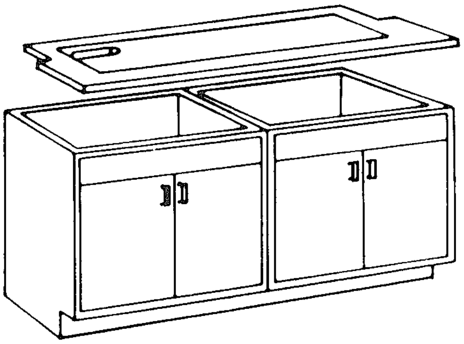
Glazing Material	
• Tempered and laminated glass	Most versatile
• Laminated glass	Sharp blisters may be projected in high-energy explosions
• Tempered glass	Blunt glass when broken, but may fall away leaving no protection
• Wire glass	Wire restricts vision; sharp blisters in fire and explosion; wire corrodes
• Plain glass	Avoid use; not recommended.
• Plain plastics	Inferior to glass; may shatter dangerously in explosions

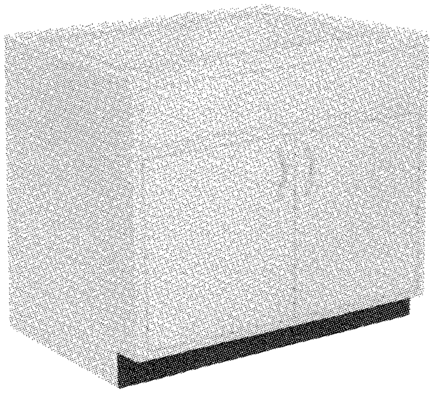
Surface coatings

Paintings and Coatings	
• Porcelain, baked Enamel	Tough, versatile
• Epoxy coatings	Tough, versatile
• Paint	Not resistant to solvents and heat

Sample specifications for lab fume hoods are shown in the Appendix section

- **Storage.** Do not provide storage shelves in hoods. Chemical storage cabinets can be located under the hood. Flammable storage cabinets can be located near by in the lab.





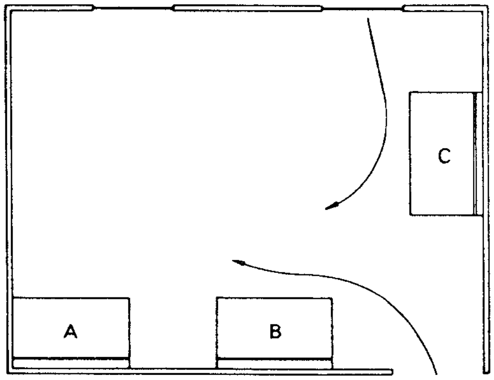
- **Location of the hood within the lab.** The best hood located in a poor location will still give poor containment performance. Always avoid placing hoods alongside walkways, near open doors and windows, or near supply air registers.

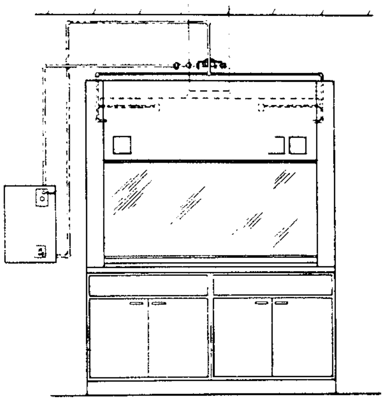
Close to utility chases

As a secondary concern, hoods should be placed as close to utility/service shafts as possible. This will reduce the amount of horizontal ductwork from the hood to the utility/service shaft.

Check fire codes

For fire safety, avoid placing hoods in the fire escape pathway, or near fire escape doors. Automated fire extinguishers can be installed in the hood and ductwork.





Answers to Exercises

Exercise 1. What is the hood static pressure when the duct velocity is 0.25 inches w.g., and the hood entry loss is 0.50 inches w.g.? (Assume STP.)

SPh = VP + He

= 0.25 + 0.50 = 0.75 inch w.g.

(The static pressure at the hood must be SP = -0.75 inches w.g.)

Exercise 2. What is the entry loss He for a lab fume hood when the average velocity pressure in the duct is 0.38" w.g.? The hood manufacturer tells us the loss factor is K = 1.88. (From the technical sales literature.)

He = K x VP = 1.88 x 0.38" = 0.71" w.g.

Exercise 3. Determine the SPh required for a lab fume hood where the duct velocity is Vd = 2,400 fpm, and the slot velocity is VPs = 1,500 fpm; let Kd = 0.25 (a tapered takeoff at the duct entrance.)

SPh = 2.78VPs + (1+K)VPd

from Chart No. 5, VPs = 0.14" w.g.
VPd = 0.36" w.g.

SPh = 2.78(0.14) + (1+0.25)(0.36) = 0.84" w.g.

Exercise 4. Suppose a solvent (methyl alcohol) is being used in a lab fume hood. The solvent use rate is known, and from that the concentration in the exhaust air is calculated to average $C_{ea} = 50$ ppm. Charcoal sampling of the lab worker's breathing zone suggests concentrations of solvent vapor, C_{bz} less than 0.01 ppm, the limits of detection. What is the minimum hood Protection factor?

PF greater than C_{ea} / C_{bz}

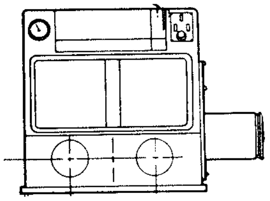
greater than 50/.01

greater than 5,000

(Optional) Exercise 5. If you have access to laboratory fume hood systems, examine the several hoods. Are the hoods intact and still built to original specifications?

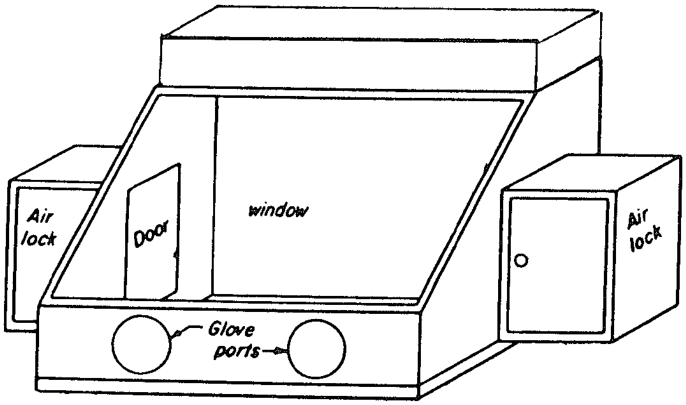
This exercise is an important effort. More detailed approaches to evaluation are provided in subsequent chapters.

Chapter 6.
Glovebox Hoods



According to the American Glovebox Society (AGS), a glovebox hood is a controlled environment work enclosure. It provides for complete separation of the work from the outside lab environment. Normally, the hood is equipped with sealed gloved openings for the protection of the worker, the environment, and/or the product. (10)

The enclosure is often maintained under a slight negative (or, occasionally positive) pressure at all times. Glovebox hoods should maintain an internal pressure (compared to the room air) of at least ±0.10 inches w.g. when closed. Some suggest ±0.50" w.g.



Useful terms:

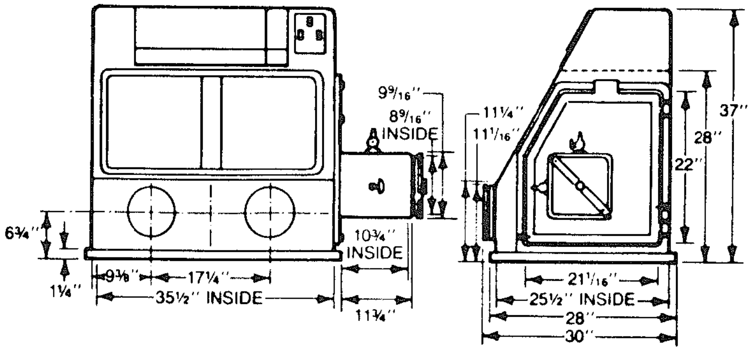
Access Panel	A removable panel used for equipment service or maintenance, or for sealed utility entrance to the hood.
Airlock	An airtight enclosure or chamber mounted on the side of the hood for passing materials in and out of the hood. The airlock allows for continuous containment.
Containment	Separation of the inside work area (and any potential contaminants) from the outside work environment.
Penetration	Any opening in the hood (e.g., for utility services) which maintains containment.

Types of glovebox hoods

There are many types and styles of glovebox hoods. Some common ones are:

For **chemicals**

The *chemical carcinogen glovebox.* This hood is used to handle a wide variety of toxic and hazardous chemicals. HEPA/charcoal filtration is often provided at the outlet of the hood. Inlet HEPA filters may be provided. Construction materials may consist of stainless steel or fiberglass. Many of these hoods have interchange chambers to allow safe transfer of chemicals and equipment.



For **bioaerosols**

The *biological and anaerobic glovebox.* These hoods handle a wide variety of biological operations. (See Chapter 8 for more detail.) The anaerobic hood may be maintained under a slight *positive* pressure, which requires a completely air-tight hood.

For **defined atmospheres**

The *controlled atmosphere glovebox*. These hoods are used to create and maintain special atmospheres (e.g., a nitrogen atmosphere.) Completely air tight, they may not be provided with exhaust ductwork. In this case, gas valves are used to create and pressurize the atmosphere, then to purge the glovebox.

For **radioactive materials**

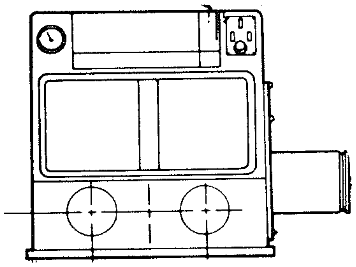
The *radioisotope glovebox.* These hoods were developed to handle various low-to-high level radioactive procedures. These hoods should meet NRC and DOE requirements. See **More Information** for standards.

For **non-containment operations** of any kind

The *Open Front Box.* This is similar to a glovebox in many respects except that the enclosure does not have gloves, or it has a narrow hand slit in front for access. It is not isolated from the lab environment.

Standards

There are two primary standards-setting organizations—the ANSI Z9 committee on industrial ventilation, and the American Glovebox Society. ANSI has included a number of glovebox requirements in its *ANSI Z9.5 Standard on Lab Ventilation.* (See Chapter 12 for more information. Copies of the standard are available from AIHA.)



There are many inconsistencies between the ANSI Z9.5 standard and the proposed AGS standards. Until some accommodations have been made, it might be wise to adopt the more stringent provisions of each standard. Each is described on the next several pages.

ANSI Z9.5

The ANSI standard covers the following topics:

Paragraph No.	Topic
5.14.1	General description and use
5.14.2	Location
5.14.3	Design and construction (materials, utilities, ergonomic design, provision for spills, exhaust ventilation, air cleaning, piping)
5.14.4	Decontamination
5.14.5	Work permits
5.14.6-11	A classification scheme for glovebox hoods:

Class A	A glovebox equipped with an airlock.
Class B	A glovebox not equipped with an airlock.
Class C	Any special purpose glovebox hood not conforming to Class A or B definitions.
Class D	An open front box.
Class E	A controlled atmosphere glovebox in which the atmosphere (or any other substance in the glovebox) is hazardous (e.g., an atmosphere of hydrogen sulfide.)
Class F	A controlled atmosphere glovebox in which the atmosphere (or any other substance in the glovebox) is not hazardous (e.g., an atmosphere of nitrogen.)

As you can see, some glovebox hoods could fit in two or more classes (e.g., A, C, and E).

The most important provision of ANSI's Paragraph 5.14 requires that glovebox hoods maintain a negative pressure of -0.10 inches w.g. when closed. When the largest opening is open, the inlet face velocity should be at least 100 fpm.

AGS standards

AGS has proposed a number of standards in its draft publication *Guidelines for Gloveboxes.* (See Reference No. 10 in the Appendix. According to the AGS office, the final AGS standard should be available in early 1994. The 150-page AGS standard covers the following topics:

Paragraph No.	Topic
1	Scope
2	Applicable Documents
3	Terms and Definitions
4	Safety
5	Design
6	Fabrication
7	Linings and coatings
8	Interior equipment
9	Installation
10	Operations
11	Maintenance
12	Decommissioning
13	Quality Assurance

Construction and Use

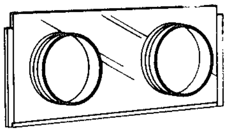
General information

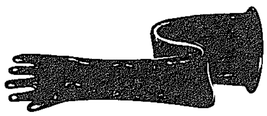
The glovebox, being an air-tight container, usually has a large window for viewing the operation. Materials are handled through arm-length, gauntlet-type gloves, usually made of rubber or plastic. Gloves must be flexible but leak-tight, resistant to the chemicals used, and resistant to punctures and abrasive leakage.

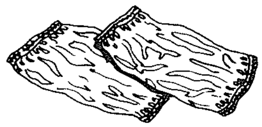
Gloves and materials

Glove materials are summarized below: (22)

Material	Features
• Natural Latex Rubber	Flexible, fair leak resistance, good resistance to acids, poor resistance to organic solvents
• Neoprene Rubber	Good leak resistance, good solvent resistance, good ultra-violet light resistance
• Milled Neoprene	Improved abrasive resistance
• Butyl Rubber	Used for special applications







Materials may be introduced to the glovebox hood through (1) ventilated shafts connecting multiple gloveboxes, (2) airlock chambers, (3) sealed containers or bags, and (4) open hatchways. Open hatchways are the least reliable and most likely to cause contamination. Airlock chambers are less reliable than sealed containers or ventilated shafts.

Maintaining containment

If a glovebox hatchway is open, if a glove should fail, or if a leak should develop anywhere in the hood, the in-flowing air should maintain a face velocity of at least 100 fpm in hoods equipped with exhaust ventilation.

In multiple-glovebox facilities, the exhaust system should be designed to automatically increase the exhaust volume of air in the event of a catastrophic failure of some part of the system (e.g, the breakage of a large window.)

Don't pick a glovebox hood unless you're willing to pay the price.

Manipulating chemicals and process equipment inside a glovebox is time consuming, expensive, and tedious. It requires special training of lab workers and their cooperation.

Because of the added difficulties, glovebox hoods are normally used only when:

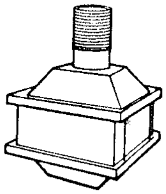
- materials are highly hazardous or toxic (e.g., carcinogens),
- materials readily disperse (e.g., very fine powders),
- materials must be kept isolated from other potential contaminants (e.g., biological materials), and
- special atmospheres must be provided (e.g., high nitrogen content.)

Typical air flow rates

Air flow rates through a glovebox typically range from 0-50 cubic feet per minute. This air flow originates from leaks in the hoods, or is introduced to the hood through small HEPA filters, valves, or ductwork. The primary reasons to allow air into the hood are (1) to keep the hood flushed with fresh air, (2) to provide mixing within the hood, and (3) to assure that air flow is always *into* the hood.

Air filtration

Exhausted air should be passed through scrubbers or filters before being released to ductwork or to the outside atmosphere. Utilities serving the hood (e.g., water, gas, air, electrical) should be designed and installed such that they do not create significant air leakage into the hood. Controls for all utilities should be located outside the hood, or be easily accessed with the gloves if inside the enclosure.

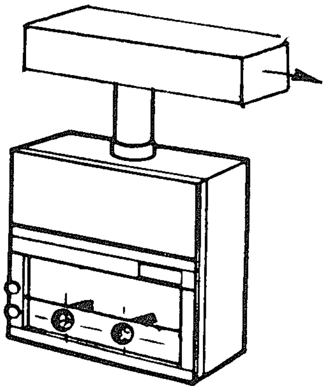


Open flames/
flammable
materials

Bunsen burners and other flame sources are not normally used in glovebox hoods. When they are, air must be supplied for combustion. If flammable gases or solvents are used in the hood, inert atmospheres should be provided (or all sources of ignition should be removed from the box.)

Gloveboxes should be located in a lab space with plenty of free movement.

Most of the math presented in the last three chapters may be applied to glovebox hoods. (Do you need to refresh your memory? Check back to Chapters 3 and 5 as necessary.)



Example 1. Suppose a glovebox is attached by a short six inch duct (Area = 0.1964 sq ft) to an exhaust plenum which also serves other gloveboxes. There is no filter between the glovebox and the plenum. (The filtration is provided somewhere downstream.) In this case, the negative static pressure serving the hood remains fairly constant. The static pressure in the duct to the plenum is SPh = -0.25 inches w.g. Suddenly a glove pops off, and falls into the glovebox. The glove port opening is six inches in diameter. (Area = 0.1964 sq ft) What minimum flow rate and face velocity could we expect if the loss factor for the hood is K = 3 for the glove-off configuration? (Assume STP.) Solution—see next page.

$\mathbf{SPh = VP_d + He}$ **and** $\mathbf{He = K \times VP_d}$, then

$SPh = VP + KVP = (1+K)VP = 4VP$

Transposing, we have

$VP_d = SPh/4 = 0.25/4 = 0.06$ inches w.g.

and

Note: the symbol " √ " is the square root, e.g., $\sqrt{.06} = (0.06)^{0.5}$

$\mathbf{V_d = 4005 \sqrt{VP}} = 4005 \sqrt{.06} = 980$ fpm

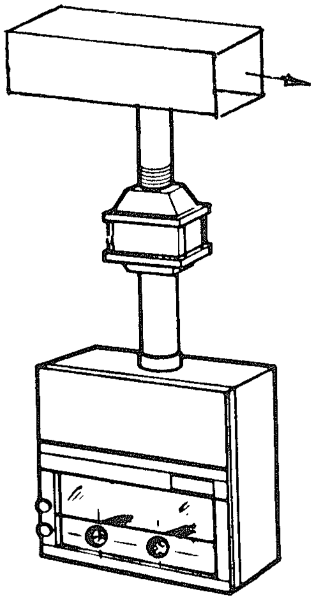
and

$\mathbf{Q = V_d A_d} = 980 \times 0.1964 = 190$ scfm

Since the diameter of the glove port is also six inches, the flow rate and face velocity are identical to that in the six-inch duct.

Exercise 1. Suppose a glovebox is attached by a four inch duct (Area = 0.0873 sq ft) to an exhaust plenum which also serves other gloveboxes. There is no filter between the glovebox and the plenum. The static pressure in the duct to the plenum is SPh = -0.15 inches w.g. Suddenly a glove pops off, and falls into the glovebox. The glove port opening is six inches in

diameter. (Area = 0.1964 sq ft) What minimum flow rate and face velocity could we expect if the loss factor for the hood is K = 3 for the glove-off configuration? (Assume STP.)



Example 2. Suppose a glovebox is attached to an exhaust plenum by a six inch duct (Area = 0.1964 sq ft). There is a HEPA filter in the duct between the glovebox and the plenum. In this case, the negative static pressure serving the hood will vary with the flow rate. The higher the flow rate, the higher the static pressure drop across the filter. The typical HEPA filter has a pressure drop which is approximately linear with flow rate (and velocity) through the filter. In other words, if the flow rate doubles, the velocity through the filter will double, and the pressure drop will also double. (This is not the case with most other losses in an exhaust system. Other losses vary linearly with the *velocity pressure*, not with the velocity.)

The static pressure in the duct (and in the plenum) after the HEPA filter is SP = -1.25 inches w.g. Suddenly a glove pops off, and falls into the glovebox. The round glove port opening is six inches in diameter. (Area = 0.1964 sq ft) What minimum flow rate and face velocity could we expect if the loss factor for the hood is K = 3 for the glove-off configuration, and product data says filter loss is SP_{loss} = 1 inch w.g. per 100 cfm? (Assume STP.)

Solution: All the losses to the plenum must sum to SP = 1.25" wg

Therefore

SP = VP + KVP + Filter loss   and

Filter loss = Q / 100 in inches w.g.

SP = VP + KVP + Q / 100

If we substitute VA for Q, and $4005\sqrt{VP}$ for V, and divide the last term by 100, we get

$SP = VP + 3VP + 40A\sqrt{VP} = 1.25$ inches w.g.

or for a six inch duct (A = 0.1964 sq ft)

1.25 inches w.g. = $4VP + 7.9\sqrt{VP}$

Solving for VP, we get VP = 0.02 inches w.g., and

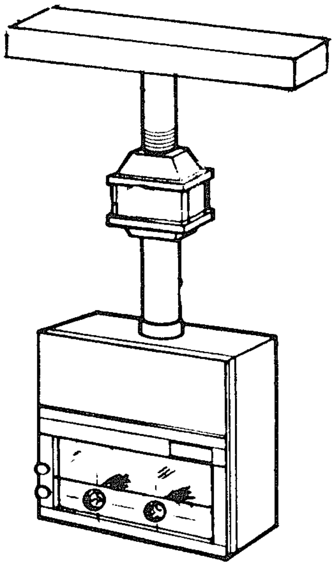
$V_d = 4005\sqrt{VP} = 4005\sqrt{.02} = 570$ fpm

and

Q = VA = 570 x 0.1964 = 110 scfm

Since the diameter of the glove port is also six inches, the flow rate and face velocity there are similar to the duct, i.e, V = 570 fpm. (The loss associated with the glove port is included in the loss factor K = 3.)

Exercise 2. Suppose a glovebox is attached to an exhaust plenum by a four inch duct (Area = 0.0873 sq ft). There is a HEPA filter in the duct between the glovebox and the plenum. In this case, the negative static pressure serving the hood will vary with the flow rate. The higher the flow rate, the higher the static drop across the filter. The typical HEPA filter has a pressure drop which is approximately linear with flow rate (and velocity) through the filter.



The static pressure in the duct and the plenum downstream from the HEPA filter is SP = -0.75 inches w.g. Suddenly a glove pops off, and falls into the glovebox. The round glove port opening is six inches in diameter. (Area = 0.1964 sq ft) What minimum flow rate and face velocity could we expect if the loss factor for the hood is K = 3 for the glove-off configuration, and the filter loss is SP_{loss} = 1 inch w.g. per 50 cfm? (Assume STP, SP still -0.75" w.g..)

Exercise 3. (Optional) If you have access to a glovebox hood, check it out. Investigate the following items: inlet filtration, exhaust filtration, air flow through the hood, static pressures serving the hood, types of material or chemicals used in the hood, the construction of the hood, and the training provided the user. Is it a safe operation? Why or why not? Outline your findings below.

Answers to Exercises

Exercise 1. Suppose a glovebox is attached to an exhaust plenum which also serves other gloveboxes. There is no filter between the glovebox and the plenum. In this case, the negative static pressure serving the hood remains fairly constant. The static pressure in the duct to the plenum is SPh = -0.15 inches w.g. Suddenly a glove pops off, and falls into the glovebox. The round opening is six inches in diameter. What minimum flow rate and face velocity could we expect if the loss factor for the hood is K = 3 for the glove-off configuration? (Assume STP.)

Since

$SPh = VP_d + He$ and $He = K \times VP_d$, then

$SPh = VP + KVP = (1+K)VP = (1+3)VP = 4VP$

Transposing, we have

$VP_d = SPh/4 = 0.15/4 = 0.04$ inches w.g.

and

$V_d = 4005 \sqrt{VP} = 4005 \sqrt{.04} = 800$ fpm

and

$Q = V_d A_d = 800 \times 0.0873 = 70$ scfm

Therefore, since the volume flow rate through the glove port will also be Q = 70 scfm, the velocity in the glove port opening will be

$V = Q/A = 70 / 0.1964 = 350$ fpm.

Exercise 2. Suppose a glovebox is attached to an exhaust plenum by a four inch duct (Area = 0.0873 sq ft). There is a HEPA filter in the duct between the glovebox and the plenum.

The static pressure in the duct and plenum after the HEPA filter is SP = -0.75 inches w.g. Suddenly a glove pops off, and falls into the glovebox. The round glove port opening is six inches in diameter. (Area = 0.1964 sq ft) What minimum flow rate and face velocity could we expect if the loss factor for the hood is K = 3 for the glove-off configuration, and the filter loss is $SP_{loss} = 1$ inch w.g. per 50 cfm? (Assume STP.)

All of the losses to the plenum must sum to SP = 0.75" w.g.

Therefore

$SP = VP + KVP + \text{Filter loss}$ and

Filter loss = Q / 50 in inches w.g.

$SP = VP + KVP + Q / 50$

If we substitute VA for Q, and $4005\sqrt{VP}$ for V, and divide the last term by 50, we get

$SP = VP + 3VP + 80A\sqrt{VP} = 0.75$ inches w.g.

or for a four inch duct (A = 0.0873 sq ft)

0.75 inches w.g. = $4VP + 7\sqrt{VP}$

Solving for VP, we get

VP = 0.01 inches w.g.

and

$V_d = 4005\sqrt{VP} = 4005\sqrt{.01} = 400$ fpm

and

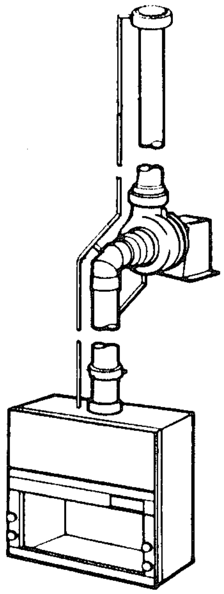
$Q = VA = 400 \times 0.0873 = 35$ scfm

Therefore, since the volume flow rate through the glove port will also be $Q = 35$ scfm, the velocity in the glove port opening will be

$V = Q/A = 35 / 0.1964 = 175$ fpm.

Exercise 3.

What will you do about the concerns you may now have?



Chapter 7. Perchloric Acid Fume Hoods

Strong oxidizer

Perchloric acid is a very strong oxidizer. It is often used to digest organic materials. The digestion procedure may volatilize all of the perchloric acid. Even when perchloric acid is simply heated above ambient temperatures in a hood, it can produce vapor. These vapors can condense and form explosives perchlorates in the hood and its exhaust system.

Case histories

Reference No. 14 describes the following accidents involving perchloric acid in hoods:

Accumulations in the ductwork

1. An explosion took place in the exhaust duct from a lab hood in which a perchloric acid solution was being fumed on a gas plate. The explosion blew out the windows, lifted the roof, and caused considerable damage to lab equipment. The hood had also been used for general chemical analysis. It was concluded that the explosion originated in deposits of perchlorates and organic materials in the duct.

Using organics in a perchloric acid fume hood

2. An explosion occurred in the ductwork serving a hood reserved for perchloric acid. A lab technician had been drying alcohol over a bunsen burner in the hood. The explosion bent the ductwork near the fan, separated the duct from the hood, and blew out several windows.

Organics and perchlorates mixed

3. A bottle of perchloric acid was accidentally dropped on the floor. Sawdust was used in the cleanup and deposited in a metal waste can. Several hours later an explosion blew the can open and started a fire. The heat activated the sprinkler system which put out the fire.

Ditto

4. The stone bench of a lab fume hood was patched with glycerin cement. Several years later, during remodeling, a workman struck the stone with a chisel. An explosion occurred. The hood had been used for digestion with perchloric acid.

Ditto

5. A conventional hood used for distillation and ashing of organic materials also used perchloric acid for digestion. During a routine ashing procedure, hot gases went up the duct, setting off a series of explosions. The duct was torn apart at several locations.

Vibrations

6. During routine maintenance involving the dismantling of a fan on a perchloric acid exhaust system, an explosion occurred following a blow with a chisel on some part of the fan housing. The explosion was heard four miles away. Two employees standing near by were injured. The man holding the chisel was killed after the chisel entered his left nostril and was embedded in his brain.

As you can see, the potential for disaster is there. It is important to keep perchloric acid and perchlorates from being permanently deposited in the exhaust ventilation system.

Containment

Limited quantities of perchloric acid vapor can be kept from condensing in the exhaust system by providing emission control at the point of operation, or at the point of origin. This can be accomplished by using appropriate containment-types of analytical equipment. (See the chemical literature for specific methods and equipment.)

Water washing

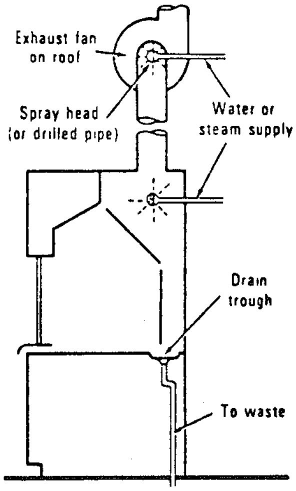
A second method is to wash deposits from the ventilation system. Perchloric acid fume hoods are constructed with special materials and water-wash capabilities.

National Fire Protection Association

NFPA 45 *Laboratory Ventilating Systems and Hood Requirements* says that if perchloric acid is heated above ambient temperatures and vapors are not trapped or scrubbed before entering the lab hood or its exhaust system, a separate hood shall be provided, designed for use with perchloric acid only, and labeled “For Perchloric Acid Operations Only.” (Paragraph 6-12.1.)

Dedicated hood

In practice, any use of perchloric acid or perchlorates warrants the use of a special, dedicated hood. Organic materials should not be used in a hood using perchloric acid.



Other provisions of NFPA 45 include (numbers indicate standard paragraph number):

6-12.2 If a lab hood or exhaust system has been exposed to perchloric acid heated above ambient temperatures, tests shall be conducted for explosive perchlorates before any inspection, cleaning, maintenance, or any other work is done on any part of the exhaust system or hood interior.

A simple and sensitive test for perchlorates uses 0.1 percent methylene blue in water. A few drops of the test solution in a small quantity of water washed from the surface to be tested will produce a violet precipitate if perchlorates are present.

Special construction required

6-12.3 Perchloric acid hoods and ductwork shall be constructed of materials that are acid resistant, nonreactive, and impervious to perchloric acid.

6-12.4 The exhaust fan shall be acid resistant and nonsparking. The exhaust fan motor shall not be located within the duct work. Drive belts shall be conductive and shall not be located within the ductwork.

6-12.5 Ductwork shall take the shortest and straightest path to the outside of the building and shall not be manifolded with other exhaust systems. Horizontal runs shall be as short as possible, with no sharp bends. The duct work shall provide a drainage slope back into the hood. Duct work shall consist of sealed sections. Flexible connectors shall not be used.

6-12.6 Sealants, gaskets, and lubricants shall be acid resistant and nonreactive with perchloric acid.

6-12.7 A water spray system shall be provided for washing down the hood interior and the entire exhaust system. Washing of perchloric acid hoods and the exhaust system should be performed after each use, or at the end of the day.

Good practices

Other important features of perchloric acid exhaust systems include:

- Ductwork should be constructed of stainless steel, with smooth welded seams. Stainless steel 316 is often used.
- All utility controls should be mounted outside the hood.

- Work surfaces should be water tight with a half-inch dished front and sides, and an integral trough at the rear of the hood to collect washdown water.

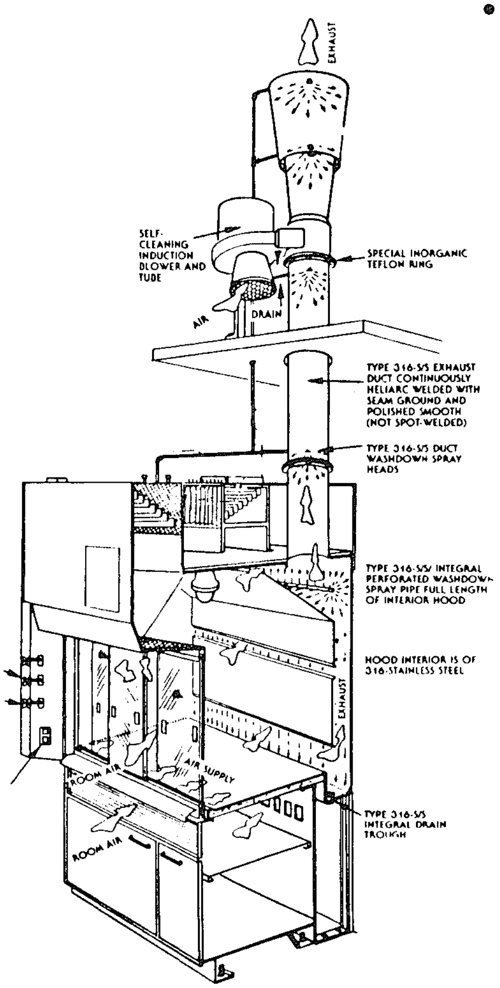
- Each perchloric acid hood should have its own dedicated duct and fan system.

- Fans should be acid and spark resistant. Injectors and induction-type blowers may be used in place of fans.

- Wet collectors, if used, should be mounted as close to the hood as possible to avoid contamination of the downstream portion of the system by perchlorates.

- Water wash down systems often consist of water spray heads located in the plenum behind the hood baffle, and along the entire duct system. Water is usually drained to the sanitary water sewer system without trouble.

- The stack should allow for maximum dispersion and protrude through the roof eddy boundary level. Ten feet is normally sufficient. See Chapter 15.


EXHAUST
SELF-CLEANING INDUCTION BLOWER AND TUBE
SPECIAL INORGANIC TEFLON RING
AIR
DRAIN
TYPE 316-S/S EXHAUST DUCT CONTINUOUSLY HELIARC WELDED WITH SEAM GROUND AND POLISHED SMOOTH (NOT SPOT-WELDED)
TYPE 316-S/S DUCT WASHDOWN SPRAY HEADS
TYPE 316-S/S INTEGRAL PERFORATED WASHDOWN SPRAY PIPE FULL LENGTH OF INTERIOR HOOD
HOOD INTERIOR IS OF 316-STAINLESS STEEL
EXHAUST
ROOM AIR
AIR SUPPLY
ROOM AIR
TYPE 316-S/S INTEGRAL DRAIN TROUGH

The adjacent figure presents a typical off-the-shelf perchloric acid fume hood. (Source: 84) Note the following items:

- 316 stainless steel construction (Fluorocarbon plastic parts, greases, or sealants may also be used. Organic materials must be avoided, e.g., organic sealants or greases.)

- Cold water washdown valves, pipes, and spray heads throughout the system. Water or fog nozzles should be of the self-cleaning type, and mounted every five feet or so, and inside of each elbow.

- Explosion-proof lighting and wiring.

- Smooth, welded seams.

- Provision for water drainage.

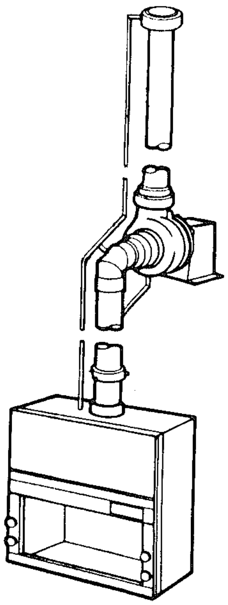
- Induction blower. (Optional) The induction blower is designed so that no mists or vapors pass through the fan itself. The fan, motor, drive, and bearings are all outside the exhaust air stream. While less efficient than traditional fan installations, and often more noisy, the additional protection may be worth the effort. The induction blower should be located on the roof, near the exhaust end of the duct system.

Assessment criteria.

Choosing a perchloric acid fume hood

Do you need a perchloric acid fume hood? They are more expensive to own and operate. The following questions should help in the assessment of need.

1. Do you have perchloric acid in the lab? In your chemical storage inventory?
2. Is perchloric acid used in any chemical process in a lab hood?
3. Is the work of a continuous nature (as opposed to infrequent use?)
4. Is the amount vaporized in the hood significant? (Microgram quantities vaporized infrequently warrants less concern.)
5. Does the acid concentration exceed 72%?
6. Does the use of perchloric acid require heating?
7. Does the operation include digestion using perchloric acid?



"Yes" answers to any of these questions would normally suggest the use of a perchloric acid fume hood. If the answer to Question No. 1 is "yes," while all others are "no," this might suggest disposing of the unused perchloric acid.

Exercise 1. Suppose you suspect contamination of a ventilation system by perchloric acid or perchlorates. What should you do?

Use water

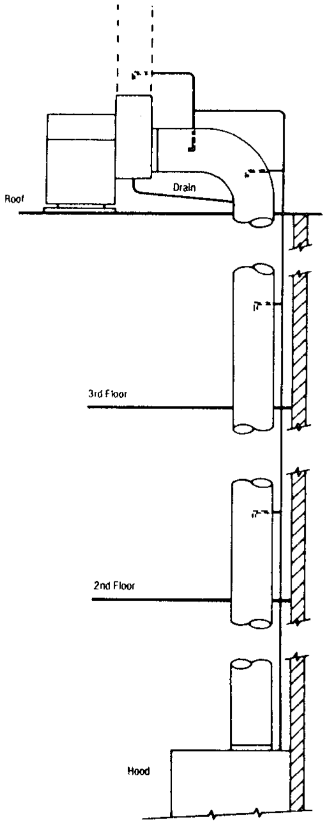
An effective method for washing down ductwork suspected of contamination by perchlorates is found in *Handbook of Laboratory Safety* (14). Written by Peter A. Breysse, it recommends steaming the ducts for 24 hours to condense water on all surfaces to dissolve and wash away perchlorate deposits. Testing should be conducted after another 24 hours and washing should be repeated until tests are negative.

Actual case history

Dismantling a lab exhaust system contaminated with perchlorates is a hazardous operation. Peter A. Breysse reported (in the *Occupational Health Newsletter,* Feb-Mar 1966, University of Washington) the following experiences and approaches used during the dismantling of systems contaminated with perchlorates (Ref. 14, edited for brevity):

> It was desired to dismantle and move six laboratory exhaust ventilation systems. Several labs served by the systems had or were using perchloric acid for wet ashing of tissues. Exhaust hoods were constructed with sharp corners and cracks, permitting the accumulation of contaminants. The ducts were made of ceramic material and contained numerous places where perchlorates could be deposited. Organic compounds were also used in duct joints, and adhesives, and as sealers for the fan. The

following procedures were used to reduce the hazards of dismantling:



1. Work was conducted on weekends to reduce the number of people potentially at risk.
2. Each system was washed for 12 hours by introducing a fine water spray within the hoods while the fan was on.
3. The fans were hosed down with water.
4. Fan mounting bolts and connectors were carefully removed, avoiding impacts. Non-sparking tools were used.
5. Fans were removed and covered with wet blankets.
6. Fans were further dismantled after additional washing and behind a steel shield for protection.
7. All disassembled parts were washed and cleaned.
8. Ductwork was thoroughly washed with water prior to and during dismantling.

These procedures for dismantling and decontamination may seem unduly strict. However, uncertainty often requires an over-careful approach.

Case Study

A Case of Panic

Your notes:

"It scared me to death," Ted said, a serious look on his face.

Ted had been discussing a new county program with a facilities engineer at a small refinery/chemical plant located on the banks of the Greene River. "Somehow, we got talking about perchloric acid. I think we were discussing water pollution. Anyway, this fellow tells me they have a water wash-down system on three lab hoods which had been dedicated to perchloric acid use." Ted shook his head thinking about the experience.

"I asked them to show me how the system worked. So this fellow offers to take me back in the lab." Ted's eyebrows went up in disgust.

"We snaked through a lot of what I thought was pretty sub-standard office space and went through a double door into what looked like some lab out of the 1930's. The place was poorly lit, noisy as hell, and cluttered and corroded beyond all comprehension. We walked to the other end of the lab and stood in front of three dilapidated and corroded fume hoods." Ted took a couple of photos from his desk top.

"See these stains here? These were eighth-inch thick buildups of crystals on the hood surface. 'And these are the perchloric acid hoods?' I asked the fellow. 'Yup,' he replied." Ted put the pictures back, sighing. "It is not very often I get excited, or panic on the job. But this was different. We immediately cleared the area. I had to throw my weight around—I even got out my health department badge. The lab and several adjacent offices were evacuated. I wasn't taking any chances."

It turned out that the water wash-down system had failed several years ago. Somehow, the buildup had escaped the notice of anyone familiar with the danger. "Or maybe they just didn't care, I don't know," Ted said.

"The interesting thing was, when a cleanup crew went to wash down the exhaust system, one of the men pulled a wooden board from the floor and it popped off—just a tiny explosion. He was thrown back without injury, but a fire started that burned part of the south wall before it was brought under control. It took the company about three months to completely clean up the mess. The costs were so high, they eventually went out of business."

Answers to Exercises

Exercise 1. Suppose you suspect contamination of a ventilation system by perchloric acid or perchlorates. What should you do?

A prudent approach might include:

- Close down the system; safeguard personnel; restrict access.
- Test for perchlorates.
- Wash the system.
- (Optional) Dismantle the system.
- Correct the procedures which allowed the contamination to occur.

Chapter 8.
Biosafety Cabinets

This chapter provides an overview of laboratory ventilation used for safety and health when handling biological materials. Much of the data for this chapter were derived from Reference No.s 12, 47, and 48. See the Appendix.

First, two terms:

Infectious agent:	Microbiological agents and their byproducts are capable of inducing disease or injury in humans, animals, or tissue cultures.
Partial containment enclosure:	An enclosure which minimizes (but does not entirely prevent) air movement from the enclosure to the lab environment. Class I and Class II biosafety cabinets.

High potential hazards

Microbiological labs and their hoods are special operations which may pose infectious disease risks to lab workers and others. The literature is filled with case histories of lab workers who contracted typhoid, cholera, glanders, brucellosis, tetanus, hepatitis, tuberculosis, tularemia, and other similar infectious diseases.

During the past few decades, those who work in microbiological labs have studied and classified various hazards and risks associated with the work. For example, CDC and NIH, among others, have provided specific descriptions of combinations of microbiological practices, laboratory facilities, and safety equipment, and has suggested recommendations for use in four categories (or biosafety levels) of laboratory operation with selected infectious agents.

Hazard levels

Biosafety Level 1 is used for education facilities using microorganisms not known to cause disease in healthy human adults.

Biosafety Level 2 is applicable to clinical, diagnostic, teaching, and other facilities using moderate-risk agents associated with human disease of varying severity.

Biosafety Level 3 is used for facilities in which work is done with exotic agents where the potential for infection by aerosols is high, and the disease may have serious or lethal consequences.

Biosafety Level 4 is applicable to practices and facilities in which work is done with dangerous and exotic agents which pose severe individual risk of life-threatening disease. Any handling of these agents create a high risk of exposure and infection.

Containment

The primary method for managing infectious agents is *containment*. Laboratory hoods and biosafety cabinets are containment devices. As always, however, the most important element of containment is strict adherence by lab workers to appropriate work practices and techniques. The following table summarizes safety equipment and containment required for various biosafety levels.

Biosafety Level	**Practices and Techniques**	**Safety Equipment**	**Facilities**
1	Standard microbiological practices	None: primary containment provided by adherence to standard laboratory practices during open bench operations.	Basic
2	Level 1 practices plus: Laboratory coats; decontamination of all infectious wastes; limited access; protective gloves and biohazard warning signs as indicated.	Partial containment equipment (i.e., Class I or II Biological Safety Cabinets) used to conduct mechanical and manipulative procedures that have high aerosol potential that may increase the risk of exposure to personnel.	Basic
3	Level 2 practices plus: special laboratory clothing; controlled access.	Partial containment equipment used for all manipulations of infectious material.	Containment
4	Level 3 practices plus: entrance through change room where street clothing is removed and laboratory clothing is put on; shower on exit; all wastes are decontaminated on exit from the facility.	Maximum containment equipment (i.e., Class III biological safety cabinet or partial containment equipment in combination with full-body, air-supplied, positive-pressure personnel suit) used for all procedures and activities.	Maximum Containment

Biosafety levels applications summary table

Laboratory types-
there are three
basic types

The basic laboratory is used for Biosafety Level 1 and 2 facilities.

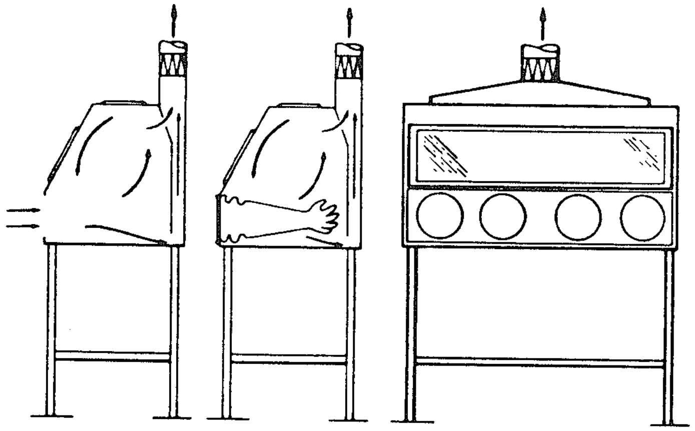
The containment laboratory has special engineering features for containment of infectious materials, and is associated with Biosafety Level 3. Special ventilation must be provided which separates the containment laboratory from other spaces. Discharged air must not be recirculated to the lab Air dispersed outdoors should not be reentrained in adjacent air handlers.

The maximum containment laboratory handles Biosafety Level 4 materials. This operation, often found in a separate building, requires special ventilation systems, airlocks, sealed openings to buildings, and other barriers. Exhaust air from the building is filtered through HEPA filters prior to discharge.

Basic hood types: Three types of containment hoods—biosafety cabinets—have been developed. Each type is given a designation—Class I, Class II, or Class III.

Class I The Class I biosafety cabinet shown in the next figure is an open-front, negative pressure, ventilated hood with a minimum inward face velocity of 75-100 fpm. The exhaust air from the cabinet is filtered by a HEPA (High Efficiency Particulate Air) filter. The cabinet can be used in three modes:

- a full-width open front,
- a closed front with holes provided for hands and arms, or
- a closed front with holes and arm-length gloves provided for access.



Class II Class II biosafety cabinets, shown in the figure following the next table, are vertical "laminar-flow" cabinets, open-fronted, with an average inward face velocity of at least 75-100 fpm. The cabinet provides user protection through inward air flow at the face of the cabinet. Product protection is provided by HEPA-filtered incoming air and environmental protection is provided by HEPA filtered exhaust air.

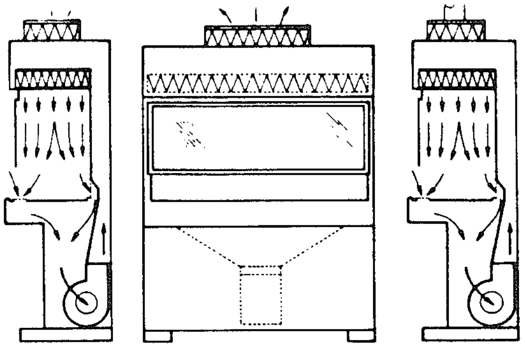
Three types of Class II cabinet

Class II cabinets are built in three basic configurations: Type A, Type B1, and Type B2. An older type (A/B3, or “Convertible”) is no longer certified for use by NSF.

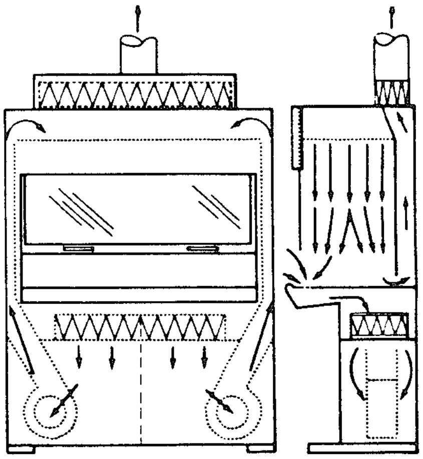
The following table summarizes typical differences between Class II cabinet types.

Type cabinet:	**A**		**B1**	**B2**
Face velocity:	75		100	100
% recirculated:	≈70		30-50	0
Exhausts to:	room or	outside	outside	outside
Exhaust duct connection:	none	canopy*	hard ducting*	hard ducting
Dedicated exhaust connection:	no	no	yes	yes
Face velocity alarm:	no	no	yes	yes
Suitable for work with toxic chemicals and radioactive materials:	no	no	small quantities	small quantities
Initial costs:	low	medium	high	high
Operating costs:	low	high	high	high

*A canopy connection maintains a space of at least one inch between the cabinet exhaust fitting and the exhaust canopy. Hard ducting is an airtight connection between the cabinet exhaust and the exhaust duct.



Type A



Type B

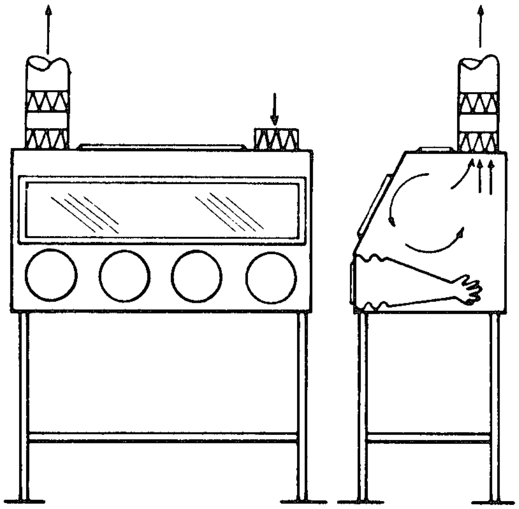
The National Sanitation Foundation issues standards, testing procedures, and accreditation

Since 1976 the National Sanitation Foundation (NSF, See Reference No. 47) has issued standards for Class II cabinets. Most recently revised in 1992, NSF Standard No. 49 describes appropriate materials of construction, design, placement, testing, and performance requirements. NSF No. 49 also requires three biological challenge tests be passed to obtain NSF certification (called "listing.") The NSF mark appears on all Class II cabinets listed by the Foundation.

Those conducting cabinet testing should be accredited by the NSF. It is suggested the cabinets be tested at least annually, when cabinets are moved, or when filters are replaced.

Class III cabinet

The Class III biosafety cabinet is a totally enclosed, ventilated cabinet of gas-tight construction. Operations are conducted through rubber gloves attached to the hood. During operation, the cabinet is maintained under a negative pressure of at least 0.5 inches w.g. Both supply and exhaust air are filtered with HEPA filtration. Exhaust air must be discharged to the outside environment through two sets of HEPA filters in series. In some cases, incineration may replace one set of filters.



The following table summarizes Biosafety Levels and the appropriate hoods to be used.

Biosafety Level	Hood Class Required
1	None required. Primary containment is to be achieved through work practices.
2	Class I or II cabinets should be used if the aerosolization potential increases the risk of exposure and disease to unacceptable levels.
3	Class I or II cabinets must be used for all manipulations of infectious materials.
4	Class III containment hoods must be used for all procedures and activities.

As noted above, air from Class I and II biosafety cabinets may be discharged into the lab environment if it is filtered through HEPA filters and tested on a regular basis (e.g., every six months for Biosafety Level 3 operations.)

Air from Class III biosafety cabinets may not be recirculated and should be discharged to the outside environment through 2 sets of HEPA filters.

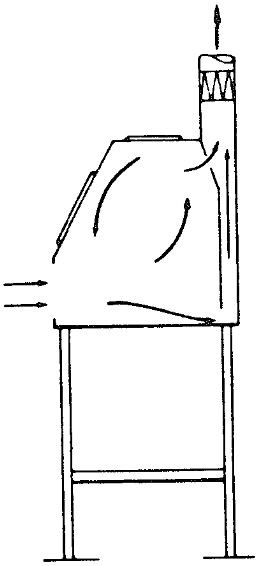
Workpractices

As with other hoods, users must be trained in the proper use of the hood. Repeated insertion and removal of the worker's arms, opening and closing lab doors, improper placement of materials in the hood, and other poor work practices will increase the fugitive emissions of aerosolized particles from within the cabinet.

Clean benches

Horizontal laminar flow "clean benches" are often used in laboratories. These so called "clean hoods" provide a high quality environment within the work chamber for protection of agents or materials used in the hood. Since the worker sits or stands in the immediate downstream exhaust air, such hoods should never be used for the handling of toxic, infectious, or sensitizing materials.

HVAC systems should be provided to provide appropriate amounts of replacement air and temperature and humidity control.

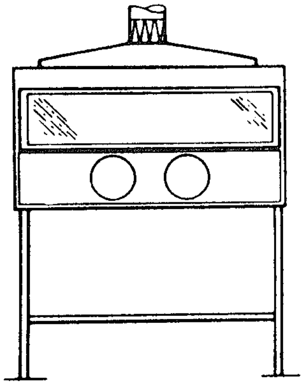


Example 1. Suppose a Class I cabinet has a face opening of 8" by 48" (No gloves). What is the minimum air flow rate required for the hood?

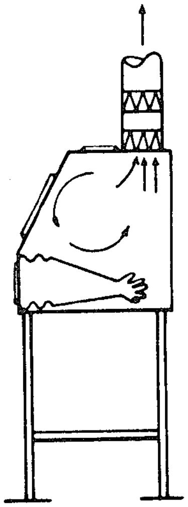
Since the cabinet requires a minimum face velocity of V = 75 fpm,

$$Q = VA = (75)(8'' \times 48'' /144) = 200 \text{ cfm}.$$

Exercise 1. Suppose a Class I cabinet has two arm openings of 8" (Round, no gloves). What is the minimum air flow rate required for the hood?



Example 2. Suppose a Class III cabinet has a leak through a flanged seam. At what velocity would air enter the hood through the leaking seam if the cabinet maintains a negative static pressure of SP = - 0.10" w.g. with the leak?



The conversion of static pressure to acceleration and entry loss follows the formula

$$\underset{\text{(loss)}}{SP = 1.78VP} + \underset{\text{(acceleration)}}{1VP}$$

The velocity pressure (VP) can be solved as

$$VP = SP/2.78 = 0.10/2.78 = 0.035\text{" w.g.}$$

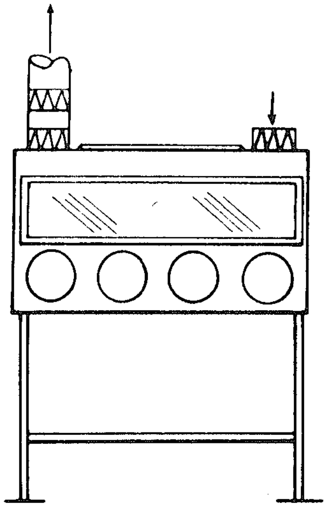
Bernoulli's equation can be used to estimate the velocity. At standard conditions,

$$V = 4005(VP)^{0.5}$$

$$= 4005(0.035)^{0.5}$$

$$= 750 \text{ fpm}$$

Exercise 2. Suppose a Class III cabinet has a leak through a flanged seam. At what velocity would air enter the hood through the leaking seam if the cabinet is maintained at a negative static pressure of SP = - 0.05" w.g. with the leak?



Exercise 3. Suppose a Class III cabinet is to be equipped with an exhaust fan. The static pressure losses are shown below:

Static pressure in the hood = 0.50" w.g., minimum

Static pressure drop across HEPA filters (manufacturers data): 1-3" w.g., at 100 cfm (1" clean, 3" at replacement).

Static pressure losses in connecting ductwork: 1.00" w.g. at a flow rate of 100 cfm.

Fans are chosen on the basis of volume flow rate and static pressure. What values of Q and SP should be used?

Answers to Exercises

Exercise 1. Suppose a Class I cabinet has two arm openings of 8" (Round, no gloves). What is the minimum air flow rate required for the hood?

Since the cabinet requires a minimum face velocity of $V = 75$ fpm,

$$Q = VA = (75)(\pi D^2 /4)(2)$$

$$= (75)(\pi)(8/12)^2 /4)(2)$$

$$= 50 \text{ cfm}$$

Exercise 2. Suppose a Class III cabinet has a leak through a flanged seam. At what velocity would air enter the hood through the leaking seam if the cabinet is maintained at a negative static pressure of SP = - 0.50" w.g.?

The conversion of static pressure to acceleration and entry loss follows the formula

$$SP = 1.78VP + 1VP$$
(loss) + (acceleration)

The velocity pressure (VP) can be solved as
$VP = SP/2.78 = .05/2.78 = 0.018$" w.g.

At standard conditions,

$$V = 4005(VP)^{0.5}$$
$$= 4005(0.018)^{0.5}$$
$$= 540 \text{ fpm}$$

Exercise 3. Suppose a Class III cabinet is to be equipped with an exhaust fan. The static pressure losses are: Static pressure in the hood = 0.50" w.g.,minimum. Static pressure drop across HEPA filters (manufacturers data): 1-3" w.g., at 100 cfm. Static pressure losses in connecting ductwork: 1.00" w.g. at a flow rate of Q = 100 cfm. What values of Q and SP should be used?

This is a difficult problem. There are no definite guidelines as how to proceed. Usually, a minimum air flow is assumed (e.g., 100 cfm) based on a *worst-case* scenario. Then, the static pressure losses are estimated and the fan chosen on that basis. If Q = 100, then the static pressure required at the fan will be

SP = 0.50" + (3" x 3) + 1" = 10.5" w.g.

We use (3" x 3) to represent the maximum loss through three HEPA filters in series. (Design is often based on the worst case condition.) When new, the filters will only have a loss of 1" each, which will initially increase the flow rate through the system unless dampers are used, or a fan with a very steep characteristic curve is chosen.

A fan can be chosen on the basis of Q = 100 cfm and SP = 10.5" w.g.

More detailed discussions of fan selection and duct design are found in Chapters 17 and 18.

Chapter 9.
The Hazardous Materials Lab

Much of this chapter is based on my experiences at the various high toxicity and radiological materials labs at Los Alamos National Laboratory (LANL, New Mexico) and with Radian's Hazardous Materials Lab (HML, Austin,Texas). See also Reference No.s 1, 10, 23, and 24 in the Appendix.)

More potential exposures

The handling of radiological materials and hazardous chemicals has also greatly expanded during the past thirty years. The creation of DOE, EPA, OSHA, and the passage of many environmental laws and regulations has created much interest in toxic, hazardous, and radiological chemicals. Research has increased the usage—and the exposure of people—to toxic and hazardous materials.

What is a hazardous material? The definition will vary between agencies, associations, and companies, but the following list describes chemicals thought to be potentially hazardous:

Chemical examples include nickel carbonyl, beryllium, and organic mercury compounds.

Radioactive examples include plutonium and tritium.

- Toxicity: TLV or PEL 0-1 ppm, or 0-0.1 mg/cu.m
- IDLH level: 0-10 ppm or 0-1 mg/cu meter
- flash point: <70 degrees F (+ toxicity also high)
- known carcinogens, mutagens, teratogens
- suspected human carcinogens
- radioactive materials with a total activity exceeding 0.1 μCi
- materials whose toxicity or radioactivity are unknown but thought to be high
- hazardous wastes of unknown composition

Not all hazardous or radioactive materials must be used and handled in RMLs and HMLs. In small quantities and under low usage rates, many toxic materials can be used and handled in normal chemical labs.

Various government and private establishments (e.g., DOE, NIH, EPA) have built dedicated radioactive materials labs (RMLs) and hazardous materials laboratories (HMLs). These facilities often provide extraordinary measures to reduce the risk to employees and the public, and to safeguard the chemicals and equipment used.

RMLs and HMLs are designed to be highly versatile, as well as to provide safe operating conditions. As you can imagine, steps taken to safeguard the lab and its occupants are sometimes heroic. This chapter highlights appropriate ventilation requirements. Other safety and health measures can be found in the literature.

Primary design and operation objectives include:

- There should be no uncontained or uncontrolled emissions of hazardous or radioactive materials into or from the lab.
- Containment of the hazardous material within secure and ventilated enclosures is required.
- Health and safety should be the prime consideration in the design and operation of ventilation systems.
- Redundancy should be provided to assure safe and reliable ventilation at all times.

High costs

RML and HML facilities are not inexpensive—$100-200 per square foot is not unusual.

Areas of risk

The RML or HML is often separated into specific zones of risk:

- Low risk zones—entrance, lobby, external offices, computer facilities, lunch room, dressing rooms, showers. No chemicals or radioactive materials are located in low risk areas.
- Medium risk zones—internal offices, general lab areas, passageways, transport areas. Unopened containers may exist in medium risk areas.
- High risk zones—isolation labs, chemical and radiological materials storage. Hazardous materials may be handled in this area.

Some provide a "moat," or a space between the higher risk areas of the lab and areas of lower risk.

The lab should be physically separated from offices and other laboratories. Various risk areas should be physically separated from each other by walls and air-tight doors and windows. Lab facilities should incorporate separate passageways for transporting hazardous materials. (Check applicable codes.)

The lab should have its own dedicated air handling systems.

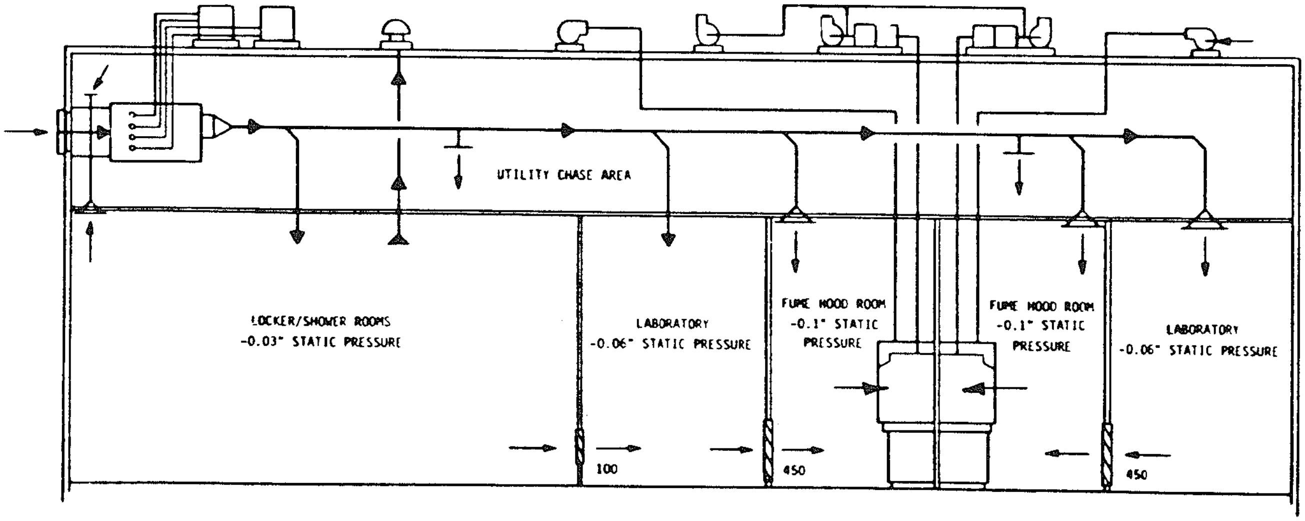
Utility access holes to the lab should be sealed (e.g., with non-flammable foams and sealants.)

Utilities, ducts, mechanical chases, and mechanical rooms should be located outside high risk areas, and be provided with a separate air handling system. That way, if an accident occurs in the lab, maintenance personnel can access utilities without high risk. A good location for all utilities is directly above the lab so that utility lines and ductwork drop vertically into the lab. This will minimize horizontal surfaces and duct runs.

Air flow patterns should be established such that air moves naturally from areas of lower risk to areas of higher risk. This helps avoid contamination of low risk areas if an accident occurs in a high risk area. This provision requires the development of pressure relationships between different areas of the lab. A static

Air should move from low risk areas to high risk areas.

pressure of 0.05" w.g. to 0.10" w.g. can be maintained by weighted dampers placed between risk areas in the lab, for example.



Exercise 1. Examine the drawing above.

Describe:

Air flow patterns:

Intended pressure drops between spaces:

Locations of utilities and ductwork:

Redundancies:

What type of hood is provided in this plan?

Provide feedback information to users

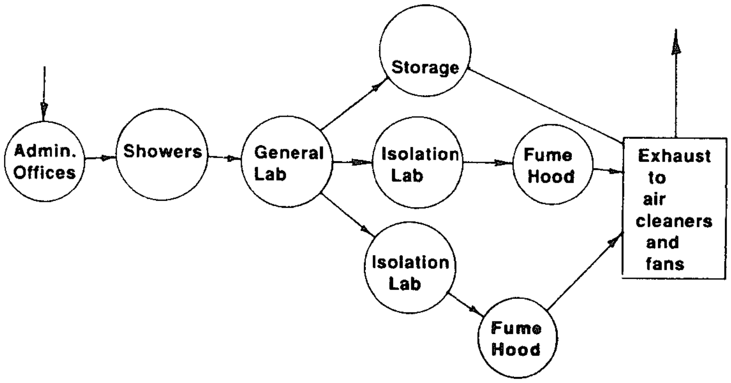
Visual and audible signals and alarms should be provided. This will assure that employees are aware of any breakdown in the normal operation of the ventilation system. These should be provided in addition to any automatic controls which may be provided.

ASHRAE 52-92 provides two tests for filters: *arrestance* and *dust spot efficiency* . Add that to the nuclear industry *DOP efficiency,* and we have at least three ways of describing filter collection efficiency.

Supply air should be filtered, tempered and conditioned. (ASHRAE Arrestance at 90% and Dust Spot at 50-60% ratings should be adequate.) This will protect equipment and chemicals, and provide comfortable work conditions for lab workers. Labs should be supplied with 7-15 air changes per hour. Studies at LANL suggest that 10-12 air changes are optimum in RMLs.

The arrestance test is a measure of a filter's ability to remove course dust; the dust spot efficiency test relates to the removal of fine dust which can cause "dust spots" in the environment served by an HVAC system; DOP efficiency refers to dioctyl phthlate particle used to test HEPA (High Efficiency Particulate Air) filters.

A typical approach is to supply air to the low risk areas and allow the air to flow naturally to high risk areas. The air is then exhausted through lab fumes hoods. Additional air is supplied to the areas of medium and high risk, as required.



No recirculation

Air should not be recirculated. All air exhausted from any lab space should normally be treated by passing the air through HEPA filtration and (for hazardous chemicals) charcoal adsorbent beds. (Check with the local air quality agency for required air cleaning.)

Redundancy

All air handling equipment should be designed with redundancy built in. For example, supply and exhaust systems should be equipped with standby fans and air cleaners. An emergency power supply should be available. For example, some labs have diesel generators standing by in the event power is lost. All air handling systems should be provided with testing devices which monitor the operation of the system. These may consist of pressure taps, flow monitors, and so forth. Most modern RMLs and HMLs have sophisticated feedback and control systems built in.

Monitoring instruments and controls for air handling systems should be located outside the lab, or in a low risk area.

The air cleaning system should also be provided with appropriate monitors and sampling ports. Again, check with the local air quality agency to determine requirements.

Stack heights are sometimes determined from dispersion modeling.

Exhaust stacks should be placed in a downwind area of the roof, and be at least ten feet above the roof line or air handling equipment. Supply air inlets should be mounted on the upwind side of the building, preferably in the upper 1/3 of the wall. Aesthetic enclosures should be avoided.

Simplicity enhances safety (but not energy or cost savings)

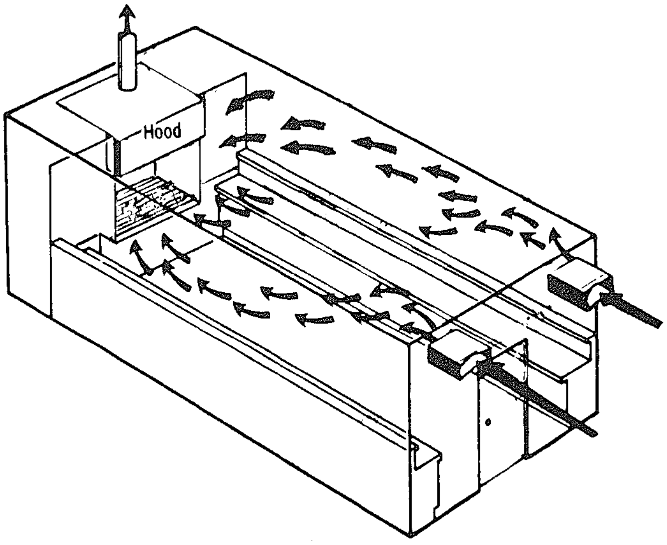
Lab hoods should normally be high-quality by-pass type hoods. On-site testing of hoods as they were installed should have met the ASHRAE 110 method of testing performance of laboratory fume hoods (19),or an equivalent test for containment performance.

Conventional or auxiliary supplied hoods should normally be avoided because of the reduced performance factors associated with these types of hoods. Where energy conservation is important, heat exchangers have proven to be safe and effective when maintained.

Where appropriate, glovebox hoods should be provided. Most high-activity RMLs use glovebox and open-face box hoods exclusively. See NRC documents for additional guidance. See also Chapter 6 and Reference 10.

Avoid turbulence outside the hood.

Hood face velocities should average 100-125 fpm, with no measurable cross drafts at the hood face. Field tests should be routinely and regularly used to test hood containment performance (e.g., smoke tests.) See Chapter 10 for testing procedures. More sophisticated testing (e.g., ASHRAE 110) may be periodically useful to assure containment of hazardous materials in the hood.



Supply and exhaust systems should be balanced. Constant volume air handling systems are preferred. If variable air volume systems are used, automatic balancing equipment should also be provided. Dampers must meet NFPA standards. Where the hazard potential is high, such as in RMLs and HMLs, simplicity should be the rule. The more automated or complex the controls, the greater the chance for malfunction.

Follow good work practices

All of the good practices noted in Chapters 4-8 should also be followed in RMLs and HMLs. Because of the potential for contamination, all open-chemical work should be performed inside a properly operating hood. Spot exhausts, canopy hoods, and slotted capture hoods are often effective for the control of routine chemical handling operations (e.g., weighing, pipeting, and so forth.)

This is now required by ASHRAE 62 -1989

A real-time monitor of flow and pressure conditions should be provided at each hood and glovebox (e.g., a hood static pressure monitor calibrated for flow.)

Safety first

Employees should be trained to understand the ventilation system, how it works, and when it is malfunctioning. Work practices should emphasize emission and exposure control. Production quotas and high speed operations should not be part of any RML or HML operation.

Answers to Exercises

Exercise 1. Examine the previous drawing carefully.

Describe:

Air flow patterns: From lower risk areas to higher risk areas.

Intended pressure drops between spaces:
Re: atmosphere, locker = -0.03" w.g.; lab = -0.06" w.g.; isolated fume hood room = -0.1" w.g.

Locations of utilities and ductwork: Above the lab and on the roof

Redundancies: Double fan, motors, air cleaners, electrical service

What type of hood is provided in this plan? An auxiliary supplied hood (not normally recommended.)

Chapter 10
Testing of lab ventilation systems

All lab ventilation systems require regular testing and monitoring.

Objectives of testing

- Determining the effectiveness of ventilation systems (hood containment, compliance with standards and specifications, room air balance, etc.)
- Establishment of baseline or start-up conditions.
- Monitoring of system performance.

Get help for complex testing

Most of us are not able to conduct in-depth testing of lab ventilation systems, particularly air supply systems which have been integrated with the HVAC system, or VAV systems. Specialized knowledge of testing and balancing is required on the these complex systems. Always obtain competent assistance. (Check with References 63 and 67 for names of those who could help in your location.)

Simple tests

This chapter provides guidelines for *simple* fielding testing. It also provides an overview of the more sophisticated hood containment test protocols and standards.

When testing a ventilation system, we want to find out:

Why test?

- Is the system operated and maintained so it will contribute to a comfortable, safe, and healthful environment?
- Does the system comply with appropriate standards and codes?
- What can be done to improve the system?

Conduct a preliminary survey, first

Prior to testing, the investigator should conduct a preliminary survey:

- Identify all lab ventilation systems, and become familiar with them,
- Determine the expected operating parameters for each system, and
- Perform cursory ventilation checks with smoke tubes and velometers.

Get help and Safety First

The preliminary survey team should include the building engineer, or a person who is familiar with the systems. ***Safety first*** should govern all testing activities.

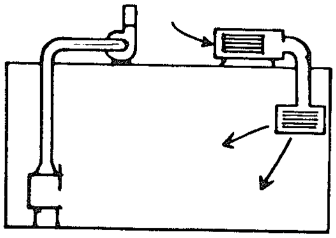
Obtain building mechanical drawings

Review the "as built" and "as modified" drawings to familiarize yourself with HVAC systems, exhaust systems, and the building mechanical layout. See Chapter 14 for information on reviewing plans and specifications.

Become familiar before beginning testing

One approach to the preliminary survey is to follow each ventilation system from start to finish. Go first to the air intakes. Follow the air as it flows through the dampers, filters, fans, coils, ductwork, terminal boxes, and supply registers. As you proceed note:

- Provision for OA, location of air intakes
- Location of dampers
- Location of filters
- Thermostat locations and temperature levels
- Supply and return register locations
- Potential sources of contaminants (chemicals)
- Location of controls
- VAV system air delivery schedule, minimums
- Location of hoods
- Location of exhaust ducts, fans, stacks
- Controls used to vary air flow rates, air temperatures



Checklist No. 14, *Inspection Checklist for Lab Ventilation Systems* can be used to organize the preliminary survey.

Exercise No. 1. Using a copy of Checklist No. 14, conduct an informal inspection of a lab available to you. (Obtain permission first. Take along the building engineer.) Make comments below.

Once you have completed the preliminary survey, you are ready to conduct additional testing as required. This may include performance testing of hoods, characterizing air supply systems, characterizing exhaust systems, and so forth. In the following pages we cover:

- An overview of quantitative hood containment performance testing methods
- Methods and equipment for field testing hoods
- Simple approaches for characterizing air supply systems

Containment Performance Testing of Hoods

During the past ten years, three containment testing methods have been published in the USA. One was issued by ASHRAE, two by EPA:

Three main methods

- ASHRAE 110 Freon Test Method
- EPA Sulfur Hexaflouride Test Method
- EPA Urinine Dye Test Method

These three standard test methods were tested by Lisa Woodrow at Los Alamos National Lab (LANL). (See Reference 26.)

Each of the methods were evaluated for:

- Variability and reproducibility
- Practical applications for field use
- The amount of leakage detected at the hood face

Containment testing was performed in both bypass and auxiliary-air supplied hood, and at five different average face velocities: 60, 80, 100, 125, and 150 fpm.

The results of the study are summarized as follows:

Results not encouraging

- There was no correlation (at the 0.01 significance level) for measured leakage between the methods (i.e., no method could be readily compared with any other method, according to this study).

- No containment test was readily suited to routine field evaluations.
- Leakage from the hood did not vary significantly over the range of face velocities.

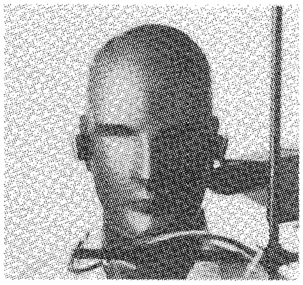
Each test is described briefly below:

[It appears that no one uses this test anymore.]

The *Urinine Dye Test Method* is a lengthy and tedious procedure using a lot of equipment. A uranine solution is placed in nine (9) #40 Devilbiss nebulizers. These are attached to a grid and located 6" inside the hood face. Each of the nebulizers discharges in a beaker to create the aerosol. Three 30-minute samples are collected on glass-fiber filters, one at the exhaust duct, two others along the plane of the hood sash. After some chemical manipulations and a reading of the urinine dye on a fluorimeter, the ratios of the readings are obtained. No guidance as to acceptable ratios is given.

[This test has not become popular, either.]

The *EPA SF_6 Method* was originally intended to be a pre-placement test. (The urinine dye test was to be used for in-place testing.) In this test, SF_6 gas is dispersed in the hood from twelve discharge points six inches inside the hood face. A real-time monitor measures the gas one inch in front of the hood and at the breathing zone of manikin. Another sample is taken from the exhaust duct. A performance factor (the ratio of the exhaust concentration vs. front-of-hood concentration) is estimated. Performance factors of 333 and greater are considered acceptable. The estimated time of testing: 2 hours per hood. (26)



This is the recommended test method in the new ANSI Z9.5 standard (although it is not required).

The *ASHRAE Tracer Gas Test* has been adopted by ASHRAE as its recommended test method. In this test, a tracer gas (e.g., SF_6) is released at a known rate inside the hood from a single dispersion nozzle. Ten-minute samples of tracer gas are obtained in the breathing zone (BZ) of a manikin standing at three different positions in front of the hood. Results are reported as:

"**xx AU yy** " or "**xx AM yy** ."

ASHRAE 110 was in the process of public review and revision as of November, 1993. Proposed new provisions include a VAV testing protocol and two less intensive levels of testing. The new provisions should make the standard more attractive to a larger number of hood users.

If you elect to perform the ASHRAE 110 tracer gas test, you should obtain the most up-to-date testing instructions from ASHRAE. More information on the ASHRAE standard is also provided in Chapters 5 and 12.

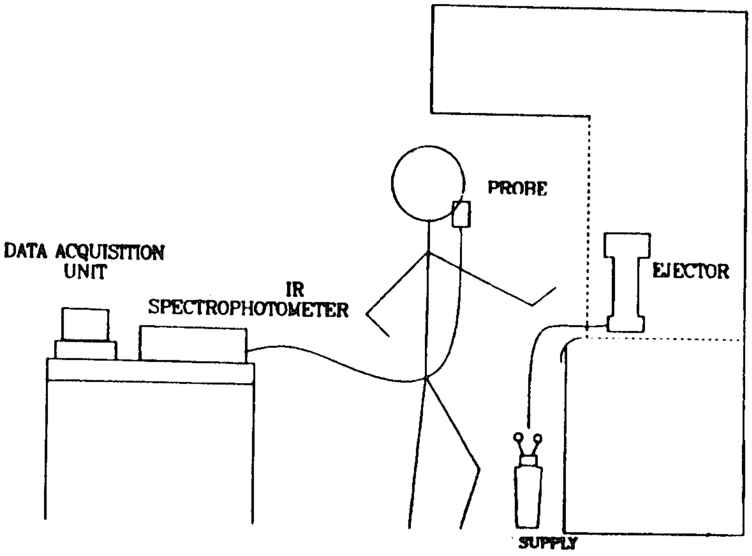
[Authors note: My preference is to have the ASHRAE test performed by the lab hood supplier at the factory on similar, generic hoods.]

The **xx** refers to the release rate of tracer gas, typically 4 lpm.

The **yy** refers to the BZ concentration, typically 0.01-0.1 ppm.

The **AU** and **AM** refer to "as used" and "as manufactured."

It has been suggested that a hood with a rating of 4 AM 0.05 provides acceptable containment. However, the standard does not specify a minimum acceptable performance. The estimated time of testing: 2 hours per hood. (19, 26)



As you can see, each of these methods requires much time, effort, specialized equipment, calibration, and highly trained and motivated testing personnel. None of the methods has been adopted (as of November, 1993) as mandatory in current codes or standards. Until such time, you may elect to rely on subjective, semi-quantitative containment testing which has been used for years with good results. Let's explore some approaches.

Semi-quantitative measures of hood performance

1. Follow traditional employee BZ sampling

One approach is simply to measure chemical concentrations in the employe's breathing zone using traditional industrial hygiene testing methods. Exposures below some acceptable level (e.g., the TLV, the PEL, the Action Level, 10% of the PEL) are subjective evidence of satisfactory containment.

2. Estimate performance factors using simple methods

Another useful approach is to estimate the ratio of the concentration of a contaminate in the exhaust air vs. the concentration in the breathing zone of a person actually working in front of the hood.

$$\textbf{Protection Factor (PF)} = \frac{C_{\textbf{exhaust air}}}{C_{\textbf{breathing zone}}}$$

For example, suppose a person is using methyl alcohol in the hood. If the concentration in the exhaust air is C_{ea} = 200 ppm, and the concentration in the breathing zone is C_{bz} = 0.2 ppm, then the Protection Factor is calculated as follows:

PF = 200/0.2 = 1,000

This approach is quite useful, and is easy to measure or predict. Indicator tubes may be used to measure the approximate concentration in the breathing zone of the hood user. More information on procedure is found in Chapters 5 and 16. Acceptable PFs must be determined by each user, and usually range from 300 to 10,000.

3. Measure traditional, subjective containment parameters

Another approach is to measure *containment performance parameters (CPP),* compare them to acceptable standards, and assume acceptable containment if standards are met. For example, if CPP test results match the following accepted parameters, containment may be assumed. (This is the method almost everyone uses.)

Subjective containment parameters

Typical containment performance parameters for a hood include:

1. No observed smoke release when tested with visible smoke.
2. Hood face velocity averages 80-120 fpm. (User determines acceptable face velocity. Face velocities of 100-120 are most common.)
3. No single measurement of face velocity exceeds ±20% of the average face velocity.
4. Air mixing velocities at the face of the hood do not exceed 40 fpm with the exhaust turned off (i.e., drafts at the face of the hood are minimal).
5. Hood users follow good work practices.
6. The hood is configured as the manufacturer intended it to be.

Field Testing Methods and Equipment

A small bag with this equipment makes an excellent field testing kit

Basic field testing devices include:

- Smoke tubes, smoke generators (e.g., titanium tetrachloride)
- Velometers, anemometers
- Pressure sensing devices (pitot tubes), manometers
- Voltage and amperage meters (to be used by qualified persons)
- Noise and vibration monitoring equipment
- Tapes and distance measuring devices
- Other: rags, flashlight, drill, drill bits, mirror, tachometer, duct tape, thermometer, psychrometer.

Simple tests you can do yourself

Typical measurements include the following:

1. Duct circumference, duct diameter, duct materials of construction, elbow radii, duct lengths, length of straight duct into fan.
2. Hood face dimensions, slot dimensions.
3. Smoke tests (subjective containment).
4. Hood face velocity, volume flow rate.
5. Duct velocity, duct volume flow rate.
6. Static pressures at the hood, air cleaner, and fan.

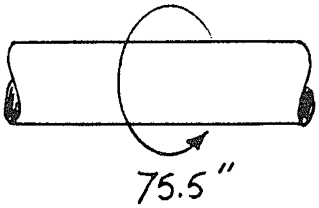
Let's see how to perform each of these measurements.

Duct measurements

1. The *duct diameter* is measured for the purpose of calculating duct area. Inside duct diameter is the most important measurement, but an outside measurement is usually sufficient on sheet metal ducts. Duct measurements are often difficult. Measuring tapes seldom lay flat against the duct, ducts are often out of round and they frequently vary from the nominal size by a small percent. So, for example, if your figures indicate a round diameter to be 20.1 inches, there is a good probability that the duct is a nominal 20" duct.

The usual method is to throw the measuring tape around the duct, obtain the circumference, and divide by π to obtain the diameter. Another is to insert the pitot tube, and measure the distance across the duct on the tube.

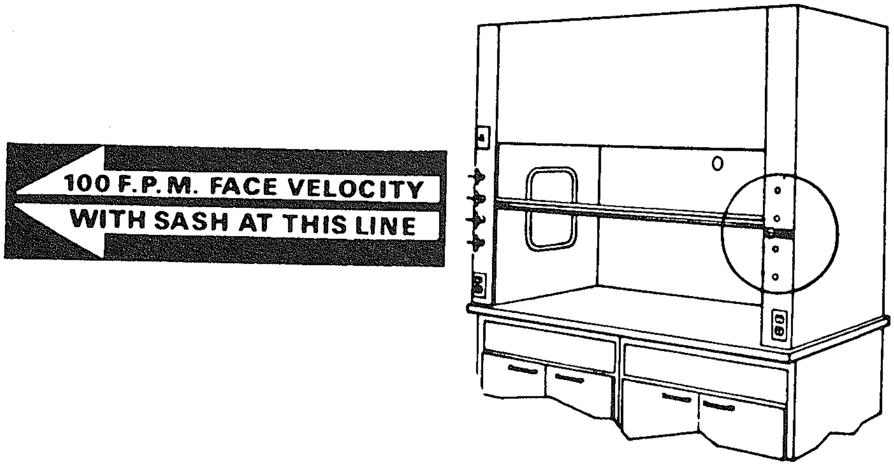
Exercise 2. Suppose the circumference of a duct is measured as 75.5 inches. What is the duct diameter?



Duct lengths can be estimated from plans, drawings, and specifications. Measurements can be made with tapes or optical measuring devices.

Hood measurements

2. *Hood face dimensions* should be measured with a tape. Measurements should be made with the sash in the wide open position and at the height specified for work in the hood. For example, many hoods have an opening 60 inches wide by 28 inches high with the sash in the up position. However, during operation the sash may be required to be placed at some other position. Sash position arrows should be used when this is the case. Actual sash stops may also be installed.



Using smoke

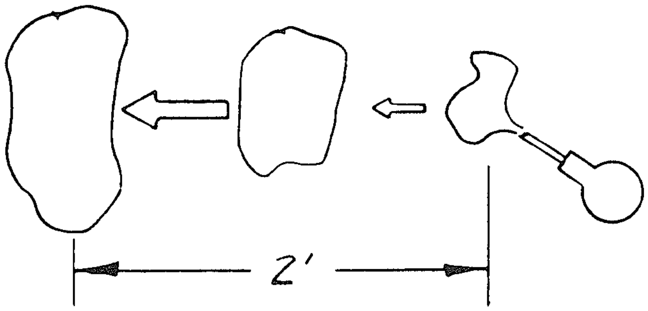
Smoke tubes are available from Draeger, MSA, Regin, and others.

3. *Smoke* is useful because it is visible. It can subjectively demonstrate *containment* of air in the hood. Nothing convinces people more quickly than to show smoke drifting away from a lab fume hood, stratifying in layers, or moving in the wrong direction.

Run an open smoke tube around the edge of the hood face. All air movement should be into the hood. *Any* leakage or reverse air flow suggests inadequate containment. (See the case history at the end of this chapter.)

If you have a smoke generator, or a smoke candle, set the device to produce smoke in the back of the hood. Any visible emission of smoke from the hood indicates inadequate containment. [Note: Prepare lab occupants for the test. Allow the hood to be configured in its actual-use mode. Notify fire authorities about the release of smoke. Prepare room occupants to evacuate the area if smoke is released to the room.]

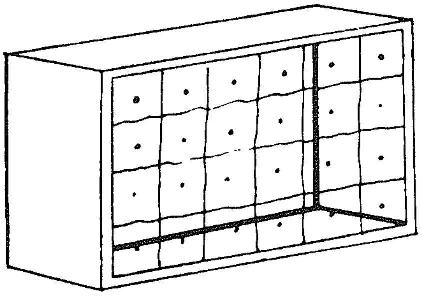
Smoke can also be used to provide a rough estimate of face velocity as shown in the next figure. Squeeze off a quick burst of smoke. Time the smoke plume's travel over two feet. Calculate the velocity in feet per minute. For example, if it takes two seconds to travel two feet, the velocity is 60 fpm.



[If you have not completed Chapter 3, please do so before proceeding.]

4. *Hood face velocities* are often used to estimate the flow rate of air through the hood.

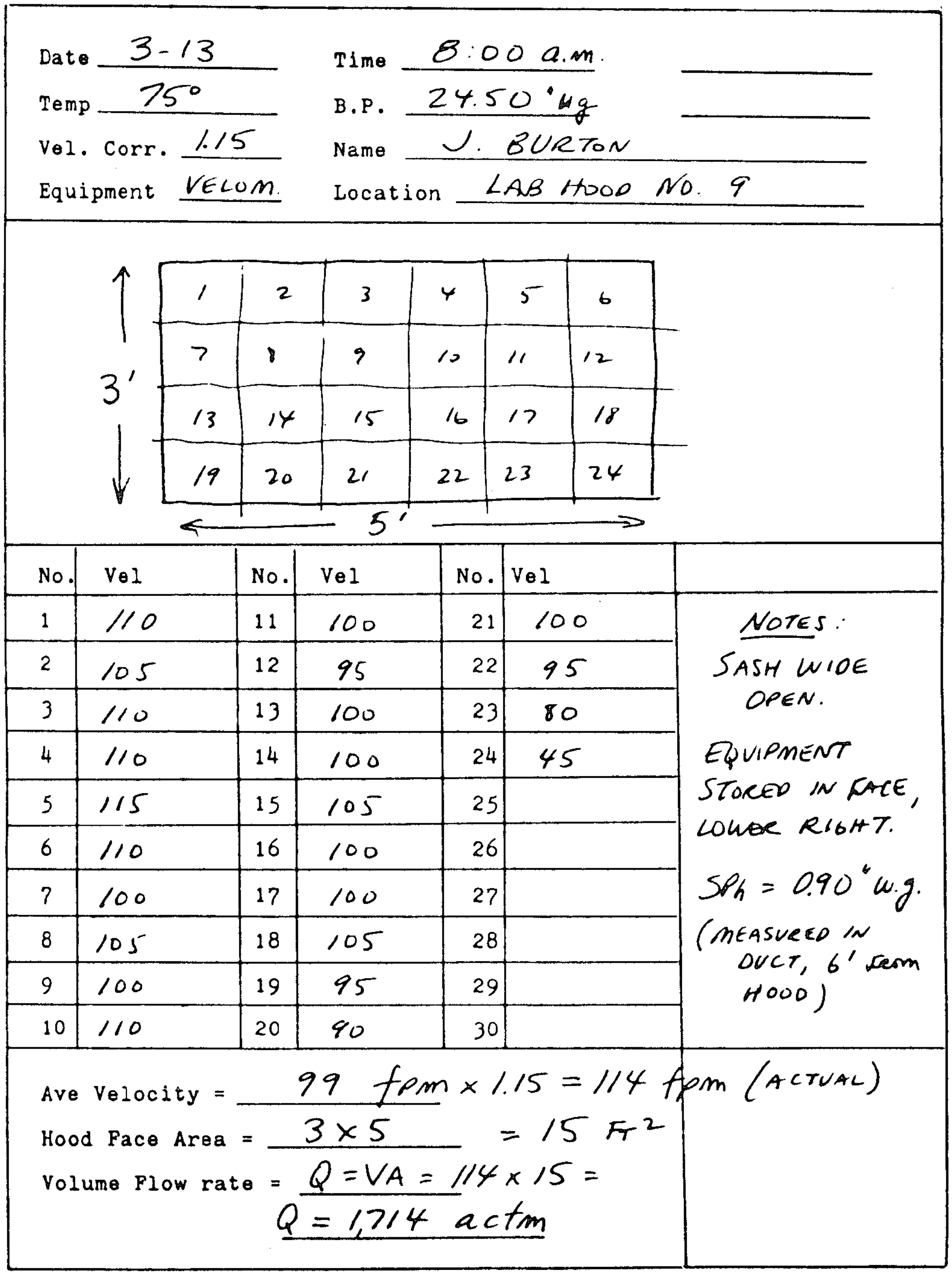
The following figure shows the method of estimating the average face velocity in a hood face. Velometers and anemometers are well suited to these measurements.



- *mark off imaginary areas*
- *measure velocity at center of each area*
- *average all measured velocities*
- *calculate range of velocities*

Form No. 3 in the Appendix is a typical work sheet. You can use it to develop one for your own use.

Example 1. A sample face velocity worksheet is shown below. Please follow the calculations shown. Please note the "velocity correction factor." Each velometer has a way of adjusting for non-standard air conditions. Check the literature which came with your equipment. (More information is provided in Chapter 20, as well.)



Date 3-13
Time 8:00 a.m.
Temp 75°
B.P. 24.50" Hg
Vel. Corr. 1.15
Name J. BURTON
Equipment VELOM.
Location LAB HOOD NO. 9

3'

1	2	3	4	5	6
7	8	9	10	11	12
13	14	15	16	17	18
19	20	21	22	23	24

5'

No.	Vel	No.	Vel	No.	Vel
1	110	11	100	21	100
2	105	12	95	22	95
3	110	13	100	23	80
4	110	14	100	24	45
5	115	15	105	25	
6	110	16	100	26	
7	100	17	100	27	
8	105	18	105	28	
9	100	19	95	29	
10	110	20	90	30	

NOTES:

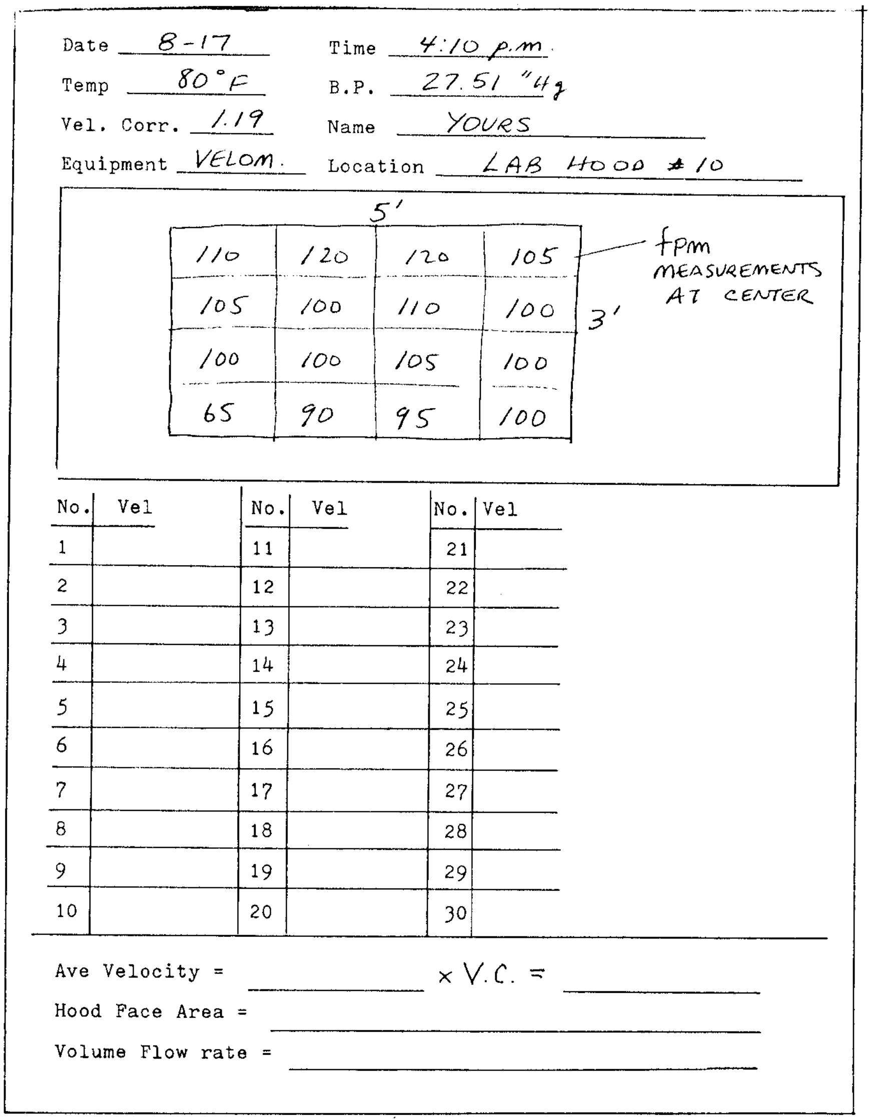
SASH WIDE OPEN.

EQUIPMENT STORED IN FACE, LOWER RIGHT.

SP_h = 0.90" w.g.
(MEASURED IN DUCT, 6' FROM HOOD)

Ave Velocity = 99 fpm × 1.15 = 114 fpm (ACTUAL)
Hood Face Area = 3 × 5 = 15 FT²
Volume Flow rate = Q = VA = 114 × 15 =
Q = 1,714 acfm

Exercise 3. A face velocity worksheet is shown below. Please complete the calculations. [Note: SPh measurement is usually obtained along with VP measurements.]



Date 8-17

Time 4:10 p.m.

Temp 80°F

B.P. 27.51 "Hg

Vel. Corr. 1.19

Name YOURS

Equipment VELOM.

Location LAB HOOD # 10

5'

110	120	120	105
105	100	110	100
100	100	105	100
65	90	95	100

3'

fpm MEASUREMENTS AT CENTER

No.	Vel	No.	Vel	No.	Vel
1		11		21	
2		12		22	
3		13		23	
4		14		24	
5		15		25	
6		16		26	
7		17		27	
8		18		28	
9		19		29	
10		20		30	

Ave Velocity = ____________ × V.C. = ____________

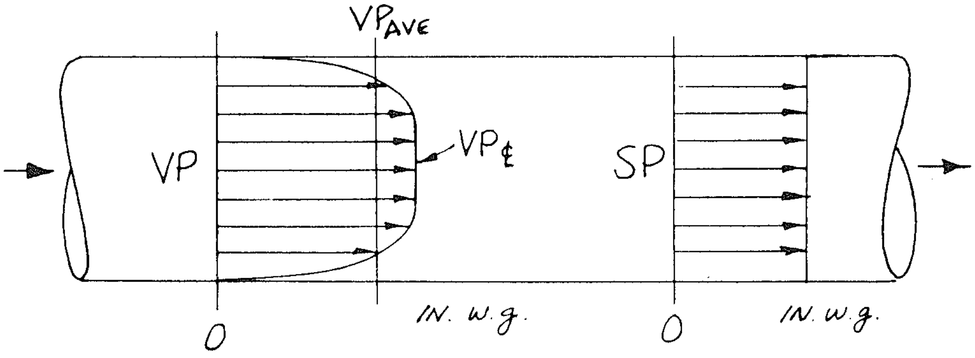
Hood Face Area = ____________

Volume Flow rate = ____________

[Please complete Chapter 3 before continuing.]

5. *Duct velocities* are sometimes used to estimate volume flow rate.

Air flow in ducts is almost always turbulent, with a small boundary layer at the surface of the duct. The next figure shows typical velocity profiles in round ductwork.



Since velocity varies with distance from the edge of the duct, a single measurement is not usually sufficient.

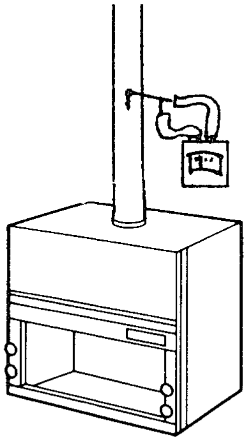
Notice the following about long straight sections of duct:

- the velocity at the edge of duct is V = 0
- the velocity at the centerline is the maximum encountered (usually—there may be exceptions)
- the average velocity is somewhat less than the centerline velocity.

Shortcuts

One way of estimating the average velocity in a long straight section of duct is

$$\mathbf{V_{ave} = 0.9 \times V_{centerline}}$$



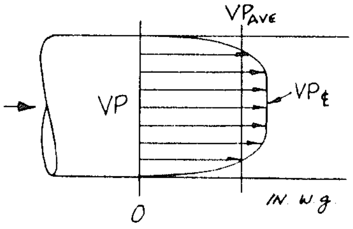
and if we substitute Bernoulli's equation for V,

$$\mathbf{VP_{ave} = 0.81 \times VP_{centerline}}$$

A long straight section usually means at least five duct diameters downstream and three duct diameters upstream from any bend, obstruction, transition, etc.

Example 2. The centerline velocity in a straight duct near the hood is V = 1,800 fpm. What is the predicted average duct velocity?

$V_{ave} = 0.9 \times V_{centerline} = 0.9 \times 1800 = 1{,}620$ fpm

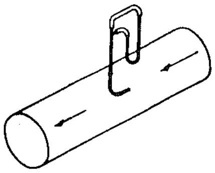


Exercise 4. The centerline velocity pressure in a straight duct is VP = 0.33" w.g. What is the predicted average duct velocity pressure?

Once we have an estimate of the average duct velocity, the volume flow rate can be estimated.

Q = VA

Example 3. A 12 inch diameter, round, exhaust duct is attached to a lab fume hood. At five diameters downstream the centerline VP is 0.31 inches w.g. What is the volume flow rate in the duct. In the hood?

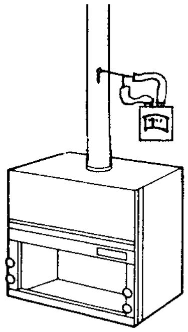


$VP_{ave} = 0.81 \times VP_{centerline} = 0.81 \times 0.31 = 0.25$" w.g.

Using Chart 5, we see Q = 1500 scfm

(Line up VP = 0.25 and D = 12", read $Q_{duct} = 1500$)

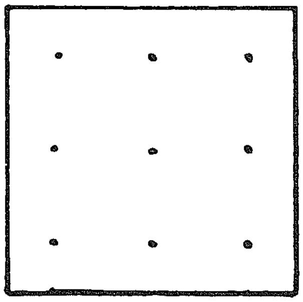
Flow rate at the hood is the same, Q = 1500 scfm.

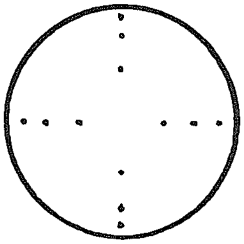


Exercise 5. A 10 inch diameter, round, exhaust duct is attached to a lab fume hood. At five diameters downstream the centerline VP is 0.19 inches w.g. What is the volume flow rate in the duct. In the hood?

Pitot traverse

A more accurate method of measuring velocity pressure is the pitot tube traverse. In a pitot traverse, a number of VP measurements are made on each of two (or three) traverses across the duct, 90° (or 60°) opposed. Measurements are made in the center of equal areas. See the next figures.

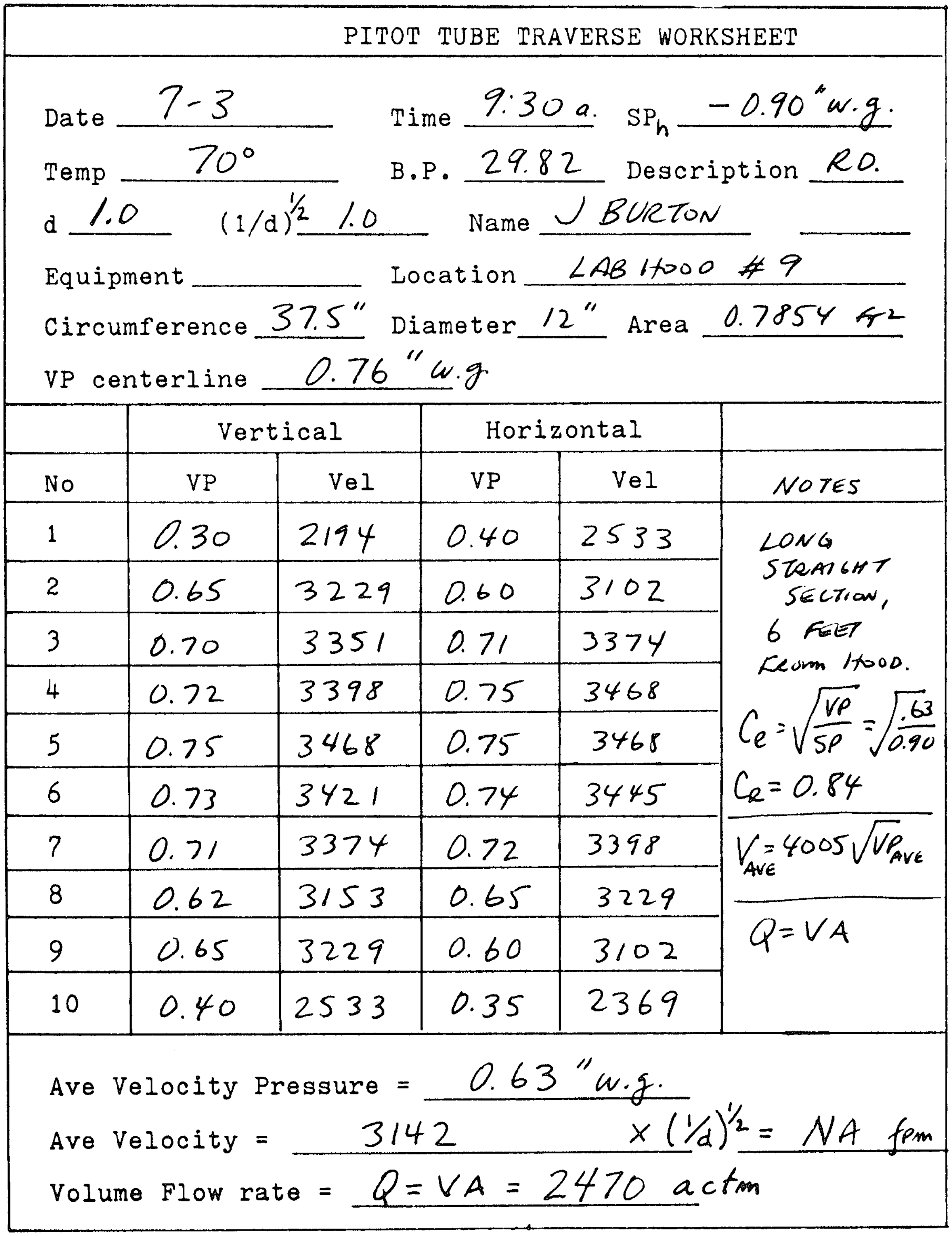




After all of the measurements are completed, each VP measurement is converted to velocity. The average velocity is then estimated.

A typical pitot traverse work sheet is provided in the Appendix (**Form No. 4**) Prior to actually conducting tests, read additional reference materials (e.g., Reference No. 3.)

Example 4. A sample pitot traverse worksheet is shown below. Please examine the calculations closely.



PITOT TUBE TRAVERSE WORKSHEET

Date 7-3 Time 9:30 a. SP_h −0.90 "w.g.

Temp 70° B.P. 29.82 Description RO.

d 1.0 $(1/d)^{1/2}$ 1.0 Name J BURTON

Equipment Location LAB HOOD # 9

Circumference 37.5" Diameter 12" Area 0.7854 ft²

VP centerline 0.76 "w.g.

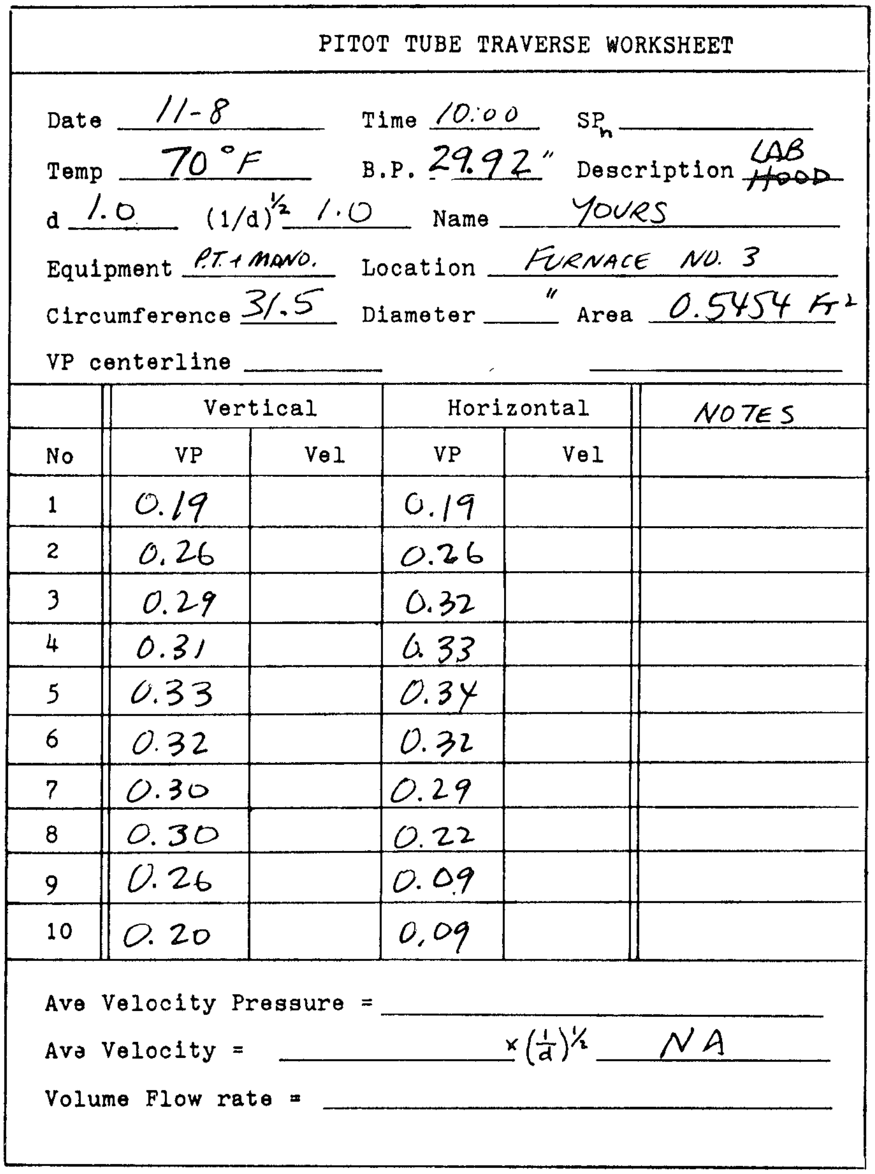
	Vertical		Horizontal		
No	VP	Vel	VP	Vel	NOTES
1	0.30	2194	0.40	2533	LONG STRAIGHT SECTION, 6 FEET FROM HOOD.
2	0.65	3229	0.60	3102	
3	0.70	3351	0.71	3374	
4	0.72	3398	0.75	3468	$C_e = \sqrt{\frac{VP}{SP}} = \sqrt{\frac{.63}{0.90}}$
5	0.75	3468	0.75	3468	
6	0.73	3421	0.74	3445	$C_e = 0.84$
7	0.71	3374	0.72	3398	$V_{AVE} = 4005\sqrt{VP_{AVE}}$
8	0.62	3153	0.65	3229	
9	0.65	3229	0.60	3102	$Q = VA$
10	0.40	2533	0.35	2369	

Ave Velocity Pressure = 0.63 "w.g.

Ave Velocity = 3142 $\times (1/d)^{1/2}$ = NA fpm

Volume Flow rate = Q = VA = 2470 acfm

Exercise 6. A sample pitot traverse worksheet is shown below. Please complete the calculations.



PITOT TUBE TRAVERSE WORKSHEET

Date 11-8 Time 10:00 SP_h

Temp 70 °F B.P. 29.92" Description LAB HOOD

d 1.0 $(1/d)^{1/2}$ 1.0 Name YOURS

Equipment P.T. + MANO. Location FURNACE NO. 3

Circumference 31.5 Diameter " Area 0.5454 Ft^2

VP centerline

	Vertical		Horizontal		NOTES
No	VP	Vel	VP	Vel	
1	0.19		0.19		
2	0.26		0.26		
3	0.29		0.32		
4	0.31		0.33		
5	0.33		0.34		
6	0.32		0.32		
7	0.30		0.29		
8	0.30		0.22		
9	0.26		0.09		
10	0.20		0.09		

Ave Velocity Pressure =

Ave Velocity = $\times (\frac{1}{d})^{1/2}$ NA

Volume Flow rate =

[Because of its usefulness and importance, an indepth look at SPh is provided in the next chapter.]

6. *Hood static pressure* (SPh) should be measured about 2-6 duct diameters downstream in a straight section of the hood takeoff duct. The measurement can be made with a pitot tube, or a static pressure tap in the duct sheet metal. The hood static pressure is an excellent method of providing a constant, real-time test of hood performance.

In non-standard air, corrections will be required. See Chapter 20, Non-Standard Conditions and follow monitoring equipment instructions.

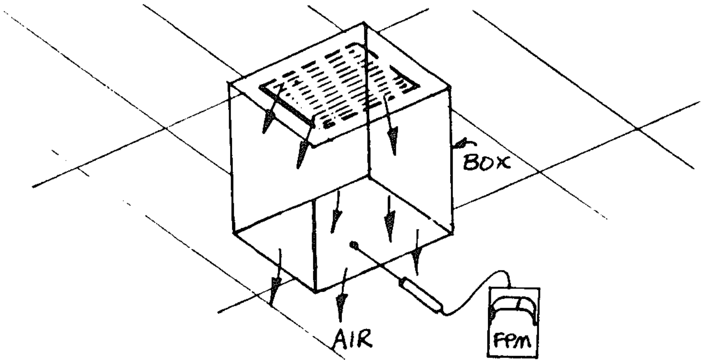
Testing Air Supply Systems

Air supply and makeup air systems

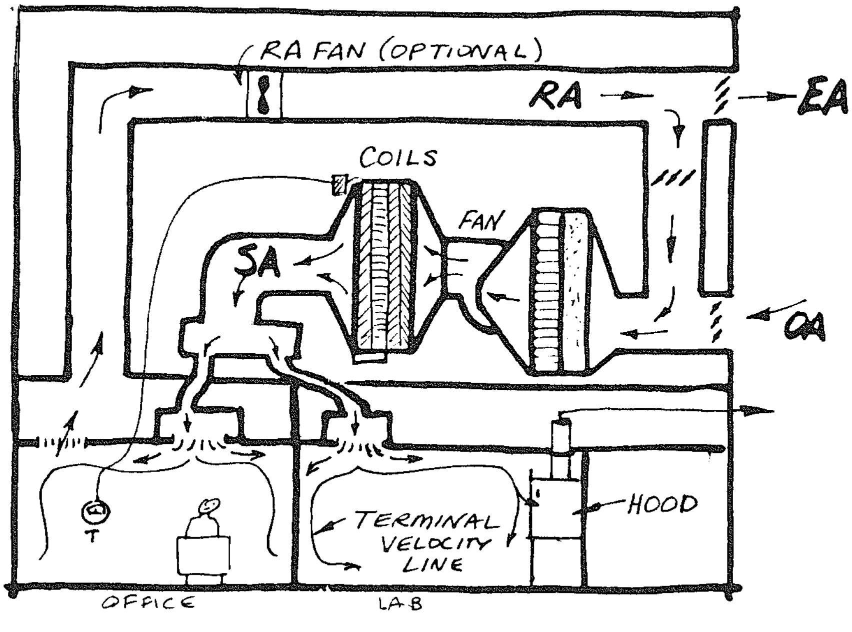
As mentioned at the beginning of the chapter, characterizing air supply/HVAC systems is complicated, and probably beyond the expertise of most people. However, simple measurements can be useful. These are described below.

Air supply rate. Locate the supply registers. They are normally in the ceiling.

- Check that air is actually flowing into the room (using smoke tubes, or your hand.)
- Check air flow at doors and windows. (Use smoke tubes. Check at top and bottom of opening. If you use a velometer, estimate the average air velocity and the volume flow rate.)
- As necessary, measure the air flow rate into the room through supply registers. (Follow the instructions on your velometer for measuring air velocities at registers.) Another approach is to place an open cardboard box over the supply register. Measure the velocity of air exiting the box.



- Compare the exhaust volume with the supply volume. Typical air replacement systems supply about 90% of the exhaust volume flow rate (when the lab is kept under a slight negative pressure.) If sufficient air is not supplied by the ventilation system, where is the makeup air coming from? (From another hood? From adjacent spaces? From outside the building? Under the door?)
- Find the approximate terminal velocity line of the supply air. Check that air is not blowing on the hood face. See the next figure. Outdoor air (OA) is mixed with return air (RA), is filtered and conditioned, and distributed to offices (on the left) and labs (on the right). Normally, the air hugs the ceilings and walls and losses its velocity. The *terminal velocity* line is 25-50 fpm. In the figure, the terminal velocity line impinges against the hood face, disrupting face velocities and reducing the containment performance of the hood.



- Are there any free standing fans in the lab to provide cooling or air mixing? (This is almost always a poor practice.) Remove them.
- Other simple HVAC measurement techniques are described in Reference No.s 3-5.

Case Study

The Isolation Lab

Your Notes:

Ted and June took lunch with a local newspaper reporter. They went to the County Cafeteria. Packed with lunchtime diners, the cafeteria was noisy and hot, so the three went to the lawn outside the building. The sun was warm, but a breeze and a large tree provided the trio with a cool, quiet place to sit and chat.

"It was quite a problem," Ted said, lifting a sandwich to his mouth.

"We put a lot time in on this one," June said, acknowledging the toughness of the case.

It all started when a lab worker was sent home sick from a local chemical company. "This particular lab takes in contract samples from a hazardous waste-dump cleanup project out in Snidersville," June said. "We've been watching this project for some time. It is toxic stuff they're finding out there—PCBs, benzene, lead-based organics, and a host of other bad actors."

"I was assigned to check the lab before the project started," Ted mused. "I was impressed—it was a well-equipped hazardous materials lab. They had everything in order—isolation labs, brand-new bypass hoods, good face velocities with the sash wide open—up around 125 feet per minute with less than 10 percent variation." Ted rubbed an apple on his shirt, its shine coming through. "They had it all—good work practices, and no previous problems. Protection factors were estimated to be over 10,000; and the ASHRAE 110 test at the supplier's plant had come in at 4AM0.01—an excellent result."

"So you can imagine how surprised I was when the report came in about the employee complaints," June said. "Actually, it turned out that the man wasn't really sick—just complaining. But when I visited the lab I could definitely smell solvent odors coming from chemicals used in the hood in his Isolation Lab. We shut that operation down immediately, and took the chemicals back to storage." June finished her yogurt, and continued. "I couldn't see anything wrong. We started the hood up again and I checked the face velocities and containment with a smoke tube. There were no apparent leaks. I took some notes on the hood and planned on sending our lab hood team out to investigate."

Exercise 7. What possible problems might have caused chemicals in the hood to be emitted to the isolation lab?

June had taken the following notes: "By-pass hood; sash wide open; hot plate in the hood; static pressure tap shows static pressure correct at SPh = 0.95" w.g.; face velocity = 125 fpm, range 115-135 fpm; no smoke leakage; hood empty; work practices, unknown; top slot, 1/4 inch open, middle slot 2 inches, bottom slot, 2 inches; no chemicals in the hood."

Subsequently, a monitoring team had been sent to the lab to check out the hood. Everything was in order. "Tests were conducted without the operation running, however," June said. "That was our problem."

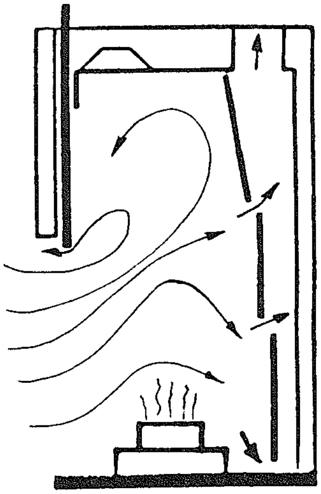
Ted continued the story. "The guys on our lab testing team ran the ASHRAE 110 containment test using a manikin. They ran the test with the hood empty but as it was configured—flow rates, damper settings, slot positions, sash up, and so forth. These EPA and ASHRAE tests take a lot of time and effort, and they can tell you a lot about a hood's containment in the environment, but they don't tell you how the hood operates with a real person standing there, working in the hood, with actual operations being conducted in the hood."

"Yeah," June mused. "I read the monitoring team's report—nothing out of the ordinary, except for the narrow top slot. I took a drive over there and asked the lab supervisor to recreate the chemical operation, with the lab technician who was there on the day of the problem. Of course, we didn't actually get out the real chemicals. We boiled some water on the hot plate in place of the actual chemicals.

"After everything was in place, I first checked the velocity of air into the hood with a velometer. It showed the same values as before—maybe a little higher average--about 125-130 fpm into the hood. There was little variation at any point, except at the top of the hood, just below the upraised sash. At that position, I measured about 50 fpm with a lot of turbulence. This was right at the top of the hood—within about 1-2 inches of the sash."

Exercise 8. What appears to be happening?

June continued with her experiences. "I got out my smoke tubes and was stunned to see air leaking from the top 1-2 inches of the hood. My velometer had tricked me, because it is non-directional. I thought I was reading 50 fpm *into the hood*, when in fact it was 50 fpm out of the hood." June stopped to enjoy a smile. She looked at Ted with a little shake of her head.



"It was that damn hot plate. It was sending warm, steamy air into the top of the hood. The narrowed top slot didn't allow for the exhaust of that air before the buoyant force caused a leak along the top edge of the hood. We opened the slot, and saw a dramatic difference—no more leakage."

Ted finished the story. "After we noted the problem, I checked a hood in our lab that had a single bunsen burner in it, but with the top slot closed. There was leakage—it was amazing."

Exercise 9. What do we learn from this case study?

Exercise 10. Turn to Form No. 5 *Lab Ventilation Deficiency Report Form.* Review it. If you have access to a lab, perform a deficiency review of the operations in the lab using Extra Form 5. Make comments below.

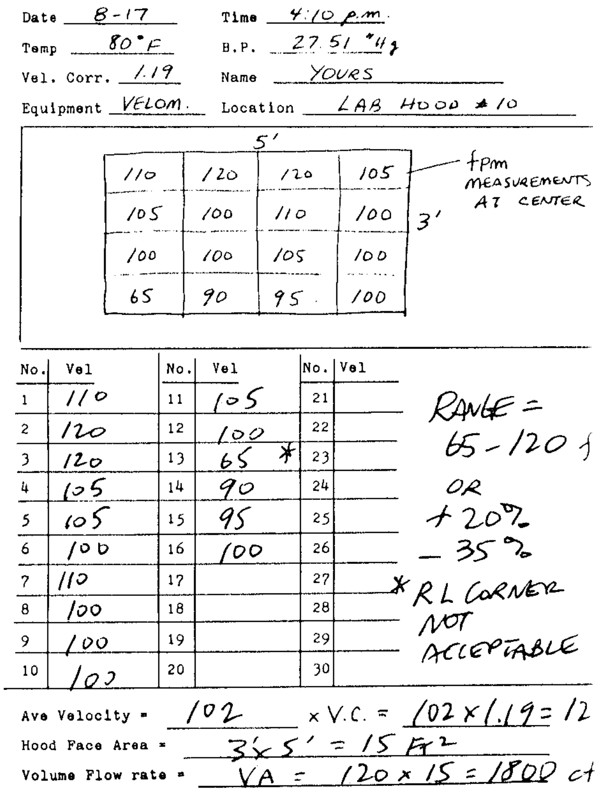
Answers to Exercises

Exercise No. 1. Good exercise.

Exercise 2. Suppose the circumference of a duct is measured as 75.5 inches. What is the duct diameter?

$D = C / \pi = 75.5 / \pi = 75.5 / 3.142 = 20$ inches

Exercise 3. A face velocity worksheet is shown below. Please complete the calculations shown.



Date 8-17 Time 4:10 p.m.
Temp 80°F B.P. 27.51 "Hg
Vel. Corr. 1.19 Name YOURS
Equipment VELOM. Location LAB HOOD #10

5'

110	120	120	105
105	100	110	100
100	100	105	100
65	90	95	100

3'

fpm MEASUREMENTS AT CENTER

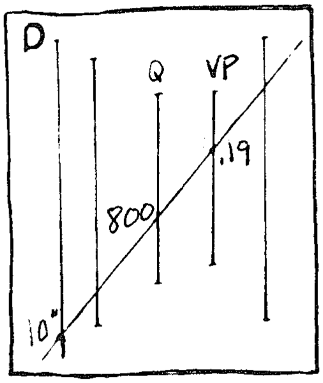
No.	Vel	No.	Vel	No.	Vel
1	110	11	105	21	
2	120	12	100	22	
3	120	13	65 *	23	
4	105	14	90	24	
5	105	15	95	25	
6	100	16	100	26	
7	110	17		27	
8	100	18		28	
9	100	19		29	
10	102	20		30	

RANGE = 65 - 120 f
OR
+ 20%
− 35%
* R L CORNER NOT ACCEPTABLE

Ave Velocity = 102 × V.C. = 102 × 1.19 = 12
Hood Face Area = 3' × 5' = 15 ft²
Volume Flow rate = VA = 120 × 15 = 1800 cf

Exercise 4. The centerline velocity pressure in a long straight duct is VP = 0.33" w.g. What is the predicted average duct velocity pressure?

VPave = 0.81 x VPcenterline = 0.81 x 0.33 = 0.27" w.g.

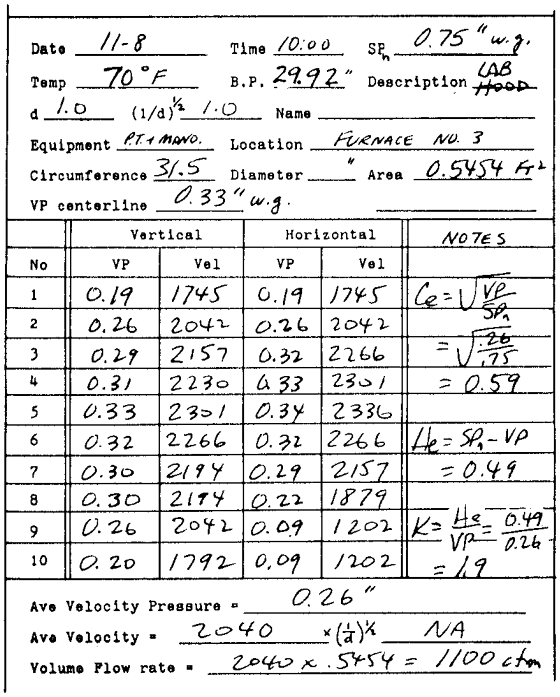


Exercise 5. A 10 inch diameter, round, exhaust duct is attached to a lab fume hood. At five diameters downstream the centerline VP is 0.19 inches w.g. What is the volume flow rate in the duct. In the hood?

$VP_{ave} = 0.81 \times VP_{centerline} = 0.81 \times 0.19 = 0.15$" w.g.

Using Chart 5, Line up VP = 0.15 and D = 10", read Q = 800

Exercise 6. A sample pitot traverse worksheet is shown below. Please complete the calculations.



Date 11-8 Time 10:00 SP_h 0.75" w.g.

Temp 70°F B.P. 29.92" Description LAB ~~HOOD~~

d 1.0 $(1/d)^{1/2}$ 1.0 Name

Equipment P.T. + MANO. Location FURNACE NO. 3

Circumference 31.5 Diameter " Area 0.5454 ft^2

VP centerline 0.33" w.g.

	Vertical		Horizontal		NOTES
No	VP	Vel	VP	Vel	
1	0.19	1745	0.19	1745	$C_e = \sqrt{\frac{VP}{SP_h}}$
2	0.26	2042	0.26	2042	
3	0.29	2157	0.32	2266	$= \sqrt{\frac{.26}{.75}}$
4	0.31	2230	0.33	2301	= 0.59
5	0.33	2301	0.34	2336	
6	0.32	2266	0.32	2266	$H_e = SP_h - VP$
7	0.30	2194	0.29	2157	= 0.49
8	0.30	2194	0.22	1879	
9	0.26	2042	0.09	1202	$K = \frac{H_e}{VP} = \frac{0.49}{0.26}$
10	0.20	1792	0.09	1202	= 1.9

Ave Velocity Pressure = 0.26"

Ave Velocity = 2040 $\times (\frac{1}{d})^{1/2}$ NA

Volume Flow rate = 2040 x .5454 = 1100 cfm

Exercise 7. What possible problems might have caused chemicals in the hood to be emitted to the isolation lab?

Poor work practices, leaking chemicals containers, and an inoperable hood could all be suspected.

Exercise 8. What appears to be happening?

Check out June's story.

Exercise 9. What do we learn from this case study?

First, nothing is obvious. Second, even the most sophisticated testing schemes may not uncover real-life problems of hoods actually being used. Third, velometer tests of face velocity must be backed up with smoke tests. Fourth, hot sources in a hood require the top slot to be open.

Chapter 11.

Function and usefulness of the hood static pressure

Hood static pressure, SPh, is easily measured and can reveal a great deal about a laboratory hood and its exhaust system.

Exercise 1. What is hood static pressure, SPh?

(You may want to review Chapters 3 and 5.)

Hood static pressure represents (1) the energy required to accelerate the air from rest outside the hood to duct velocity inside the duct, and (2) the losses associated with hood/duct entry, known as the hood entry loss, He. Numerically, SPh can be expressed as

[It is easier to use the absolute value of pressure in all equations using hood static pressure.]

$$|SPh| = VP_{duct} + He$$

where

$$He = K \cdot VP_{duct}$$

K is the hood loss factor. K = 2 for many low slot-velocity hoods. Check with manufacturer for actual loss factors. A more detailed discussion of hood entry loss calculations is provided in Chapter 5.

Combining these two formulas give

$$|SPh| = (1 + K) \cdot (VP_{duct})$$

Throughout the rest of the chapter, we use the absolute value of SPh.

Determining air flow rate changes

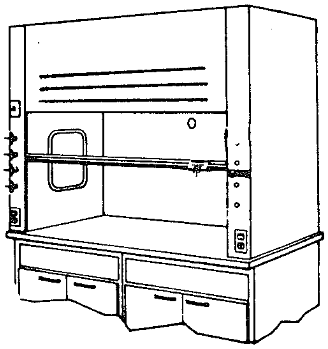
SPh and Q are related.

Hood static pressure can be a good indicator of the air flow rate through a *bypass-type* lab fume hood. The bypass hood maintains a constant volume flow rate, and the hood static pressure remains fairly constant with the sash at any position. Conventional hoods change the shape of the hood as the sash is lowered, so hood static pressure is less useful as the sash approaches the fully-closed position. However, if the sash and hood slots are always placed at the same position during the measurement, conventional hoods can also be monitored with SPh.

Conventional hood SPh should be measured with the sash and all slots at their fully-open positions.

Under these circumstances air volume changes are related to hood static pressure through the fan laws:

$$Q_{(new)} = Q_{(initial)} \bullet \left(\frac{SPh_{(new)}}{SPh_{(init)}}\right)^{0.5}$$



Example 1. Assume a bypass-type lab fume hood is exhausting 1,000 cfm of air and the hood static pressure was measured originally at SPh = 0.75 inch w.g. Three months later the hood static pressure is SPh = 0.50 inch w.g. Assuming continued standard conditions and no changes in the hood construction, air flow through the hood has been reduced by how much? (Note: We are using the absolute values of hood static pressure.)

Initial Conditions	New Conditions
SPh = 0.75 inch w.g.	SPh = 0.50 inch w.g.
Q = 1,000 scfm	Q = ?

$$Q\ (new) = 1{,}000\ \text{scfm}\ \left(\frac{0.50\ \text{inch}}{0.75\ \text{inch}}\right)^{0.5}$$

$$= 1{,}000\ (0.817)$$
$$= 817\ \text{scfm}$$

Exercise 2. Assume a conventional lab fume hood is exhausting 970 cfm of air with the sash at the full open position, and the hood static pressure was originally measured at SPh = 0.85 inch w.g. Two months later the hood static pressure is SPh = 0.66 inch w.g. with the sash at the full open position. Assuming continued standard conditions and no changes in the hood, air flow through the hood has been reduced by how much?

Initial Conditions	New Conditions
SPh = 0.85 inch w.g.	SPh = 0.66 inch w.g.
Q = 970 scfm	Q = ?

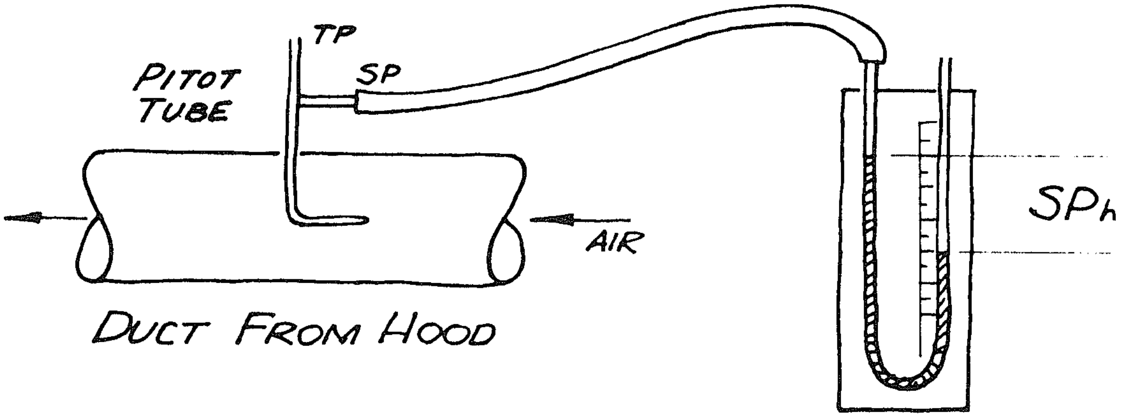
Measuring hood static pressure

Hood static pressure can be measured through a small hole, ideally about ten duct diameters (but more practically about 2-6 duct diameters) downstream from the hood in a straight section of the takeoff duct. The idea is to get beyond the influence of the *vena contracta* and its turbulence. If a hood has an immediate elbow, go beyond the elbow to make the measurement. In this case the elbow becomes part of the hood.

Pitot tube

Hood static pressure can be measured with a pitot tube and a U-tube manometer or other devices. See the next figure. SPh is the difference in the water level in the U-tube manometer, measured in inches of water.

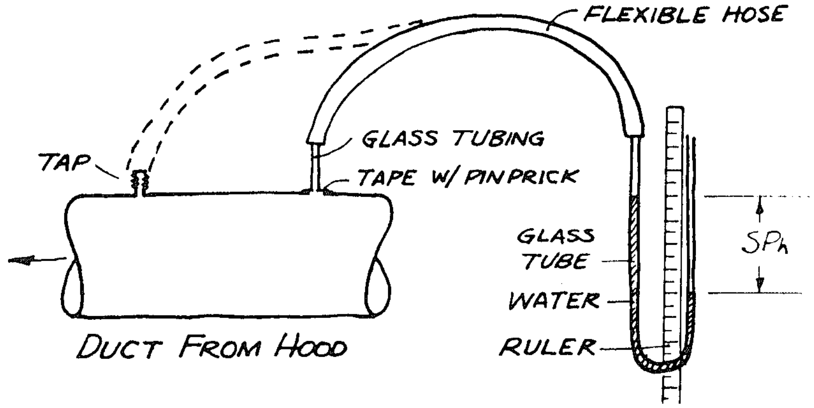
System testing is described in more detail in Chapter 10.



Simple approach

If a pitot tube is not available, an adequate estimate of hood static pressure can be obtained using a short length of glass tubing, tape, some plastic or tygon hose, a piece of glass tubing bent into a U-shape, and a ruler. See the next figure. The measurement must be taken with an airtight seal between the tubing and the tape. A little moisture (e.g., saliva, water, oil) will help.

Where a more permanent fixture is desired, a hose tap can be soldered to the duct. The tap hole, in either case, should be smooth with no projections into the air stream.



Hood Performance

Performance can be measured as a hood's ability to convert SPh to VP

Hood static pressure is useful for estimating a lab hood's ability to convert static pressure into velocity pressure VP, which is directly related to air flow rate.

Between 40-90% of the hood static pressure is converted to useful flow in the form of velocity pressure. One measure of hood efficiency (the ratio of actual flow to ideal flow) is the Coefficient of Entry, **Ce.** Ce can be related to SPh through the following formulas,

$$\mathbf{Ce} = \left[\frac{\mathbf{Q}\ \text{(actual volume flow rate at SPh)}}{\mathbf{Q}\ \text{(ideal, had all SPh} \longrightarrow \text{VPduct)}}\right]$$

substituting, we can derive

$$\mathbf{Ce} = (\mathbf{VP}/\mathbf{SPh})^{0.5} \qquad \text{(at STP)}$$

substituting again, we can also derive

Hood static pressures must be the absolute values of pressure, regular units.

$$\mathbf{Q} = (\mathbf{4005})(\mathbf{Ce})(\mathbf{A})\sqrt{\mathbf{SPh}} \qquad \text{(at STP)}$$

Where the Coefficient of Entry has not been measured, a value of Ce = 0.6 is often considered close enough for rough estimates for many low pressure lab fume hoods (e.g., SPh less than 1.25 inches w.g.).

Hood manufacturers have measured the Coefficient of Entry for their hoods. Ask for the information if you do not know. For existing hoods, and where the manufacturer cannot give you the information, Ce can be measured. (See Chapter 10 and Reference No. 4 for more information.)

The Coefficient of Entry can be measured for every hood. (Be sure conventional hoods are always measured with the sash and slots in the wide open position.)

Once established for a specific lab hood, the Coefficient of Entry never changes unless the hood shape physically changes. For example, if the sash of a conventional (non-bypass) hood is lowered to the almost-closed position, the Coefficient of Entry will change.

Example 2. Assume the hood static pressure in a lab fume hood duct is SPh = 1.05 inch w.g., and the Coefficient of Entry is estimated to be Ce = 0.6. (The actual flow rate is about 60% of the ideal flow because not all the static pressure was converted to velocity pressure.) The takeoff duct is 12" in diameter. What is the estimated air flow rate? (Assume STP.)

From the above equations,

$$Q = (4005)(Ce)(A)(SPh)^{0.5}$$
$$Q = (4005)(0.6)(0.7854)(1.05)^{0.5}$$
$$Q = 1900 \text{ scfm} \quad \text{(rounded)}$$

Exercise 3. Assume the hood static pressure in a lab fume hood duct is SPh = 0.88 inch w.g., and the Coefficient of Entry had previously been measured at Ce = 0.58. The takeoff duct is 10" in diameter. What is the estimated air flow rate? (Assume STP.)

Daily inspection and maintenance

Because SPh is simple to measure, it is not difficult to equip a hood with a permanent manometer for continuous evaluation of the hood. It's easy to train workers to read the manometer. ("If you see the water level drop below 1.0" or exceed 1.5" on the manometer, call us.")

Answers to Exercises

Exercise 1. What is hood static pressure, SPh?

Hood static pressure represents (1) the energy required to accelerate the air from rest outside the hood to duct velocity inside the duct, and (2) the losses associated with hood/duct entry, known as the hood entry loss, He. Numerically, SPh can be expressed as

SPh = VP (duct) + He (absolute values)

Exercise 2. Assume a conventional lab fume hood is exhausting 970 cfm of air with the sash at the full open position, and the hood static pressure was measured at 0.85 inch w.g. Two months later the hood static pressure is 0..66 inch w.g. with the sash at the full open position. Assuming continued standard conditions and no changes in the hood, air flow through the hood has been reduced by how much?

Initial Conditions	New Conditions
SPh = 0.85 inch w.g.	SPh = 0.66 inch w.g.
Q = 970 scfm	Q = ?

$$Q\ (\text{new}) = 970\ \text{scfm}\ \left(\frac{0.66\ \text{inch}}{0.85\ \text{inch}}\right)^{0.5}$$

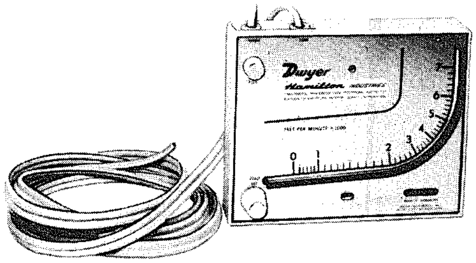
$$= 970\ (0.881)$$
$$= 850\ \text{scfm}\ \ (\text{rounded})$$

Exercise 3. Assume the hood static pressure in a lab fume hood duct is SPh = 0.88 inch w.g., and the Coefficient of Entry is Ce = 0.58. The takeoff duct is 10" in diameter. What is the estimated air flow rate? (Assume STP.)

$$Q = (4005)(Ce)(A)(SPh)^{0.5}$$

$$Q = (4005)(0.58)(0.5454)(0.88)^{0.5}$$

$$Q = 1200 \text{ scfm} \quad \text{(rounded)}$$



Chapter 12
Standards and codes

Who ultimately has responsibility for laboratory health and safety? Or more specifically, for lab ventilation systems? Under current law, the laboratory owner, operator, or employer is charged with these responsibilities.

Checklist No.s 9 and 10 (and to some extent, No. 11) outline management actions which should be taken.

Exercise 1. Turn now and review Checklist Nos 9-11. If you have access to a lab, write deficiencies below. (If you do not have access, consider a lab you are familiar with from the past.)

Always use recognized standards

Those responsible usually attempt to meet recognized standards and codes. There are a number of standards and codes which effect or influence laboratory ventilation.

Three basic types

Standards come in three basic categories:

- those which are *government sponsored* (hence, obligatory),
- those which are *association or group sponsored* (often obligatory, but under different pressures), and
- those which you develop for your own in-house use. The OSHA 1450 regulation *Occupational Exposures to Hazardous Chemicals in Laboratories* requires lab owners to develop plans and policies for their labs.

The primary government-sponsored codes which may impact lab ventilation are those promulgated and enforced by local building and fire codes and OSHA.

Association and group sponsored standards are sometimes called advisory, consensus, or voluntary standards. Major associations and private agencies interested in lab ventilation issues include UL, NFPA, ASHRAE, ANSI, SMACNA, AMCA, ACGIH, AIHA, ASTM, ASME, TABB, ISA, and SAMA.

More Information and **Chart No. 2** provide addresses for these groups.

American Industrial Hygiene Association

AIHA is an association of industrial hygienists which has been active in laboratory safety and health for over 50 years. AIHA is the parent group (the “Secretariat”) for the ANSI Z9 committee which has issued a standard on Laboratory Ventilation.

American Conference of Governmental Industrial Hygienists

ACGIH is an organization of governmental industrial hygienists. Some years ago they began publishing the *Ventilation Manual,* now in its 21st edition (as of 1994). They also provide a list of exposure standards (TLV's) and guidance on laboratory hood design (Section 10).

Air Moving and Control Association	**AMCA** is a trade association which has developed standards and testing procedures for fans. It has a number of useful publications related to fan selection, testing, troubleshooting, and certification.
Sheet Metal and Air Conditioning Contractors	**SMACNA** is an association representing sheet metal contractors and suppliers. It sets standards for ducts and duct installation.
National Fire Protection Association	**NFPA** has produced a number of recommendations which become requirements when adopted by local fire agencies (e.g. NFPA 45 lists a number of ventilation requirements for laboratories. A later subsection of this chapter describes this standard in detail.)
American Society of Heating, Refrig., and Air Conditioning Engineers	**ASHRAE** has compiled a long list of mechanical standards and codes which apply to the design and construction of ventilation systems. (See ASHRAE *Fundamentals Handbook* in **More Information.**) Of interest is ASHRAE 62-1989 *Ventilation for Acceptable Indoor Air Quality,* and ASHRAE Standard 110-1985-- *Method of Testing Performance of Laboratory Fume Hoods.* More details are provided below and in other chapters.
Scientific Apparatus Manufacturers Association	**SAMA** developed a lab fume hood standard in 1975. Although withdrawn and not now supported by SAMA, this standard contains some useful information. See a short discussion below.
Everybody knows OSHA	**OSHA** promulgates and enforces Permissible Exposure Limits (PEL) which provide allowable upper limits of exposure in the workplace. OSHA's regulation 29 CFR 1910.1450 *Occupational Exposures to Hazardous Chemicals in Laboratories* has an direct impact on lab ventilation. More later.

Building Codes

Building codes are intended to assure that buildings are built which meet certain minimum standards of construction. Their purpose is to protect the public from health and safety problems, and to retain the value of the building.

Always at the local level

Building codes are normally adopted at the local level (city, county, state) and are enforced by building inspectors. Building codes are developed by organizations: the *Basic Building Code (BBC)* of the Building Officials and Code Administrators (BOCA), the *Uniform Building Codes (UBC, UMC)* of the International Conference of Building Officials (ICBO), and the *Southern Building Code (SBC)* by the Southern Building Code Congress International.

Economic forces often influence a building owner to bring existing facilities up to current code.

Building codes are applied at the time a building is built and are not generally retroactive on older buildings unless remodeling is performed which requires a building permit.

CALOSHA. CALOSHA has a code which calls for a minimum lab fume hood face velocity of 100 fpm.

Major Standards and Codes on Lab Ventilation

ANSI Standard Z9.5 on Laboratory Ventilation

For copies, contact AIHA, the *Secretariat* for the ANSI Z9 committee. The AIHA address can be found in **More Information.**

Among the standards reviewed in the *Workbook*, this one may prove to be the most useful and influential in the years to come. (Please See Reference 38.)

The standard was issued during the final weeks of 1992 and copies of the standard became available in early 1993. The following paragraphs discuss standard requirements.

The ANSI standard is broken into eleven chapters, summarized in the table on the next page.

Chapter	Topics covered
1	Scope and objectives of the standard.
2	References
3	Definitions
4	Requirements of the standard
5	Laboratory Fume Hoods
6	Ductwork
7	Fans
8	Storage facilities
9	Dealing with catastrophes
10	Noise
11	Work practices

Does your lab comply?

Make notes here:

The standard is written with "shalls" and "shoulds" intermixed. It is more than a regulatory document--it also attempts to be a teaching tool. Important and/or unique details related to each paragraph are summarized below. (The numbers refer to standard paragraph numbers.)

1.0 The standard applies to the design and operation of laboratory ventilation systems.

1.1. The standard exempts animal labs, radioisotope labs, explosive labs, laminar flow hoods (not used for employee protection), and biosafety cabinets.

4.0 Each lab fume hood owner (called the "user" in the standard), shall select, operate, use, and maintain in good working order all laboratory ventilation equipment.

4.1 The user shall designate a "cognizant person." This is the person in the organization who has day-to-day responsibility to assure correct performance of ventilation systems.

4.2 Permanent records should be kept.

4.3 Lab fume hoods shall be used where overexposures are likely to occur.

4.4 The volume flow rate of a lab ventilation system shall be sufficient, combined with other controls, to control air contaminants to acceptable concentrations.

4.5 A replacement air system shall be provided.
4.6 Where necessary, dilution ventilation shall be provided to control fugitive emissions.
4.8 Exhaust discharge stacks shall be 10 feet above the adjacent roof line, building openings, and/or air intakes. The exhaust velocity should normally be at least 3,000 fpm.
4.10 Air exhausted from the general room area of the lab may not be recirculated unless a series of conditions are met. (See the standard for details.) Air exhausted from lab fume hoods should not be recirculated.
4.11 Supply air should provided in such a way to avoid drafts at hood faces; terminal velocities at or near hood faces should not exceed 50 fpm. Supply air should meet the requirements of ASHRAE 62 for Indoor Air Quality. Supply and exhaust systems should be balanced to provide proper flows and pressures between labs and adjacent areas.
4.12 Air cleaning should be provided in some cases.
4.13 Preventive maintenance requirements.
4.14 Testing shall be performed to assure the adequate operation of equipment serving the lab ventilation system.
5.1 Fume hoods shall be constructed of noncombustible, nonporous, corrosion-resistant materials.
5.2 Various design and construction features (e.g., airfoils, baffles, sashes).
5.3 Supply air should not create drafts in the face of the hood greater than half of the face velocity.
5.4 Hoods should be located 10 feet from any door or doorway, and away from main traffic aisles.
5.5 Work practices shall be established which minimize emissions and exposures.
5.6 Hoods shall be monitored for performance. ASHRAE 110 is the recommended test at the time of purchase and/or installation. Periodic tests of the hood function shall conducted at least annually by the user.
5.7 Hood face velocities of 80-120 fpm are considered adequate.

5.8 New and remodeled hoods shall be equipped with a real-time flow monitoring device (e.g., a hood static pressure monitoring device.)

5.10 Variable air volume hoods shall also vary the supply air to maintain appropriate balances in the lab.

5.11 Auxiliary-supplied hoods are not recommended under normal circumstances.

5.12 Perchloric acid fume hoods should meet the requirements of NFPA 45. (See discussion in previous paragraphs.)

5.13 Small exhausted rooms are not to be considered "walk-in hoods."

5.14 Glove box hoods shall maintain a negative pressure of -0.10 inches w.g. when closed; when the largest opening is open, the inlet face velocity should be at least 100 fpm.

5.16 Ductless fume hoods should be used for operations which could normally be performed on an open bench without presenting an exposure hazard unless they can meet the requirements for air recirculation in paragraph 4.12.4.2.

6.0 Ductwork shall be designed under negative pressure inside the building.

7.0 Fans shall be located outside the building or in a separate room which is maintained under negative pressure with respect to the rest of the building and provides access to fan discharge ductwork.

8.0 Storage of flammable liquids shall follow NFPA 30.

10.0 Noise associated with laboratory ventilation systems and equipment shall not exceed 85 dBA at worker locations.

11.0 Appropriate work practices should be adopted and followed; a work practices manual should be adopted for each lab.

NFPA 45 (1986 edition) **Standard of Fire Protection for Laboratories Using Chemicals**

Contact NFPA for copies

This standard applies to most lab operations and contains requirements for lab experiments and for

Does your lab comply? Make your notes here:

handling and storage of chemicals in the lab. Although devoted primarily to fire protection, it contains many provisions which impact lab ventilation. Chapter 6 "Laboratory Ventilating Systems and Hood Requirements" is of particular interest, and is summarized below, by paragraph number.

6.2 Lab hoods shall not be relied upon to provide explosion protection unless specifically designed to do so.

6.4 The location of outdoor air intakes shall be located to avoid uptake of hazardous chemicals or products of combustion.

6.4 Labs and lab areas shall be maintained at a negative air pressure relative to corridors or adjacent non-lab areas. (Exceptions exist and are noted in the standard.)

6.4 Air supply diffusers shall be selected and placed in such a way as to avoid turbulent drafts which adversely affect the performance of lab fume hoods and other exhaust systems.

6.5 Air exhausted from lab hoods shall not be recirculated.

6.5 Air exhausted from lab work areas shall not pass unducted through other areas.

6.5 Lab hood face velocities shall be sufficient to prevent the escape of contaminants generated in the hood.

6.6 Ducts from lab hoods shall be constructed entirely of noncombustible materials. (Exceptions exist and are noted in the standard.)

6.6 Controls and dampers shall be of the type that fail in the open position.

6.9 Hood baffles shall be constructed so that they may not be adjusted to materially restrict the volume of air exhausted through the lab fume hood.

6.9 Air flow indicators shall be installed on new lab hoods, or on existing hoods when modified.

6.10 Lab hoods shall be located in areas of minimum air turbulence.

6.11 Automatic fire dampers shall not be used in lab hood exhaust systems.

6.13 Lab hoods shall be labeled to indicate intended use.

6.13 A sign shall be affixed to each hood containing the following information from the most recent inspection:

- inspection interval
- last inspection date
- average face velocity
- location of fan that serves the hood
- inspector's name

6.14 Lab hoods and ventilation systems shall be inspected when installed and modified and at least annually thereafter. The inspection shall include:

- visual inspection of the physical condition of the hood, sash, and ductwork
- airflow indicator systems
- alarms
- face velocity
- verification of inward air flow over the entire hood face (this usually requires the use of a smoke test)
- changes in chemicals or work practices that may affect hood performance.

A-6.5 Ductless hoods are only suitable for use with nuisance vapors and dusts which do not present a fire or toxicity hazard.

A-6.8 Exhaust stacks should extend at least 7 feet above the roof surface to protect people on the roof.

The standard also includes provisions for hoods using perchloric acid. See the standard.

SAMA Standard for Laboratory Hoods

[Withdrawn in the early 1980's]

In December, 1975 the Scientific Apparatus Makers Association (SAMA) issued a comprehensive laboratory hood standard. It did not experience widespread use and was subsequently withdrawn. Responsibility for the standard was passed on to the Instrument Society of America (ISA). The ISA has not elected to update or actively support the standard.

The old standard established three classes of hoods, each of which was to be used for different hazard classes. A Class A hood, used for the most hazardous operations, called for face velocities of 125-150 fpm. A Class B hood, used for normal operations, called for velocities of about 100 fpm. A Class C hood was to be used for non-hazardous operations, and called for velocities averaging about 80 fpm.

The SAMA standard set forth design and construction specifications by which hoods were to be built and installed. Many hoods were built with this standard in mind, and are in use today. Thus this discussion.

It should be noted that the new ANSI Z9.5 standard for lab ventilation reduces the importance of specific face velocities and emphasizes the avoidance of cross-drafts and the use of good work practices. However, the ANSI standard does classify hoods in two classes. Chemical fume hoods are classed as Class A (a hood which meets all the requirements of the standard), and Class B (all others.) Glove box hoods are also classified, A-F.

The SAMA standard suggested two levels of hood testing. The first called for an evaluation of hoods in a test facility. These tests would be conducted by the manufacturer, or by the user at installation. The second level called for field tests by the user. These were simple tests and were intended to confirm continuing performance. A similar testing approach can be inferred from the ANSI standard.

OSHA 1910.1450
Occupational Exposures to Hazardous Chemicals in Laboratories.

One of the mandatory ones.

This rule, published in the Federal Register on January 31, 1990, covers most labs that use hazardous chemicals. The new rule took effect on May 1, 1990. Employers are obligated to maintain lab employee exposures to below the PEL through the formulation and implementation of a *Chemical Hygiene Plan (CHP).*

The CHP is broad in scope, covering work practices, management policies, handling procedures, and so forth, but should include a section or policy statement related to ventilation. (A sample ventilation management plan is included in the Appendix of the workbook.)

In the standard, OSHA cited a California study where inadequate ventilation (59%), lack of exhaust system (23%), and lack of inspection of exhaust systems (43%) were noted as significant problems in the labs studied. Obviously, lab ventilation must be an integral part of the Chemical Hygiene Plan.

Important provisions related to ventilation include: (numbers in parenthesis refer to standard paragraph numbers)

(e.3.iii) Employers are required to incorporate in their CHPs measures to assure the proper use and functioning of fume hoods. The regulation does not specify ventilation rates or face velocities.
(e.3.iii) The CHP must list specific measures that will be taken to ensure adequate performance of ventilation equipment.
(e.3.viii.B) Containment devices (such as glove box hoods) must be used with certain carcinogenic materials.

The regulation then provides (in an Appendix) NRC recommendations concerning chemical hygiene in laboratories. Although not mandatory, these provisions will certainly be viewed as important by those reading or enforcing the standard. Provisions related to lab ventilation are noted below:

(A.3) Provide adequate ventilation.
(C.1) The lab should have (a) an appropriate general ventilation system with air intakes and exhausts located so as to avoid intake of contaminated air, (b) well-ventilated stockroom and storerooms, and (c) lab hoods.
(C.2) Hoods and other control devices should undergo continuing appraisal and maintenance.

(C.3.) The work conducted should be compatible with the quality of ventilation control provided.

(C.4.a) General ventilation should: provide breathing air, provide replacement air, prevent buildup of concentrations of hazardous airborne chemicals, and provide for flow of air from non-lab spaces to labs.

(C.4.b) Lab hoods should be provided with continuous monitoring devices to allow convenient confirmation of hood performance.

(C.4.c) Other exhaust ventilation systems should be provided, as necessary.

(C.4.d) Exhaust air from glove boxes and isolation rooms should be passed through scrubbers or filters before release into regular exhaust duct systems.

(C.4.e) Modifications to ventilation systems should be made only after testing has confirmed the continued protection of workers.

(C.4.f) Where hoods are used, general air exchanges of 4-12 ac/hr is normally adequate.

(C.4.g) Air turbulence in the lab and within hoods should be avoided; hood face velocities of 60-100 should be adequate if turbulence and cross drafts are avoided.

(C.4.h) Ventilation system evaluations should be provided.

ASHRAE Standard 110 -- *Method of Testing Performance of Laboratory Fume Hoods*

The ASHRAE Standard 110 is the recommended method of testing laboratory fume hoods. See discussions of this standard in Chapters 5 and 10.

Contact ASHRAE for the latest version of the standard and information regarding testing resources.

As of November 1993, the standard was being revised. Due out about June, 1994, the revised standard will include several new testing protocols.

ASHRAE 62-1989
Ventilation for Acceptable Indoor Air Quality

This standard was published by the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) in October of 1989.

The standard applies to all occupied indoor environments, including laboratories.

The paragraphs on the following page provide the most important provisions of the new standard as they impact labs. The "shoulds" and "shalls" are taken directly from the standard. Numbers refer to the standard paragraph.

Two compliance approaches: one best suited for lab offices, one for labs.

4.0 The standard allows the user to choose one of two methods to comply: the *Ventilation Rate Procedure* and the *Air Quality Procedure.*

4.2 When the user chooses the Ventilation Rate Procedure, design documentation should clearly state this intention. Most lab *offices spaces* will use this procedure.

4.2 When the user chooses the Air Quality Procedure, more or less air may be required as compared to the Ventilation Rate Procedure. Most *lab space* will use the Air Quality Procedure, but must also meet minimum OA requirements.

When mechanical ventilation is used, provision for air flow measurement should be provided. In labs, hood static pressure measurements can be used to monitor exhaust air flow rates.

5.4 Where *Variable Air Volume Systems (VAV)* are used, and when the supply of air is reduced during times a space is occupied, indoor air quality shall be maintained throughout the occupied zone. The standard does not specifically require a minimum flow rate. However, most VAV systems should be operated such that the minimum flow is provided at all times the space is occupied.

5.5 Inlets and outlets shall be located to avoid contamination of the makeup air. See discussion of stack placement in Chapter 15.

5.7 Where practical, local exhaust systems shall remove contaminants at the source, (e.g., lab fume hoods in laboratories).

5.11 Relative humidities should be maintained between 30-60%.

5.12 AHUs shall be easily accessible for inspection and preventive maintenance.

6.1.1 Air used for ventilation of industrial operations should refer to the ACGIH *Ventilation Manual.*

6.1.3 Indoor air quality may be monitored by measuring the carbon dioxide concentrations. Concentrations not exceeding 1000 ppm are considered to be acceptable for most lab *office spaces.*

Although the ASHRAE standard is only "advisory," it will be (or already has been) adopted by local building codes, and construction plans and specification. It will be used for new construction and remodeling of existing laboratory buildings. Nevertheless, economic, labor, legal, and public forces will influence laboratory operators to bring existing facilities up to the new standard.

Economic forces come to bear because every building will be devalued by the cost of complying. Labor and public forces will put pressure on building owners because lab users will be dissatisfied to be working in "substandard" buildings.

Exercise 2. Does the ASHRAE 62 Indoor Air Quality Standard apply to laboratory operations?, Explain the rational for your answer.

Exercise 3. Does the Standard require airflow monitoring of laboratory ventilation systems? If so, what techniques would be appropriate?

Exercise 4. How far away should a lab fume hood stack be placed from the intake for a building Air Handling system to preclude reentrainment of exhausted laboratory air?

Exercise 5. Why has ASHRAE established a limit of 1000 ppm for carbon dioxide in indoor air? Does it apply in laboratories?

Exercise 6. A smoking lounge is to be installed in a small room of a large laboratory/office building. Approximately 3 people will be smoking at any one time, as a daily average. However, at lunch and at break times, as many as 10 persons may smoke. What amounts of OA should be supplied to the lounge? What other provisions are required?

ASHRAE 55-1992 Thermal Environmental Conditions for Human Occupancy.

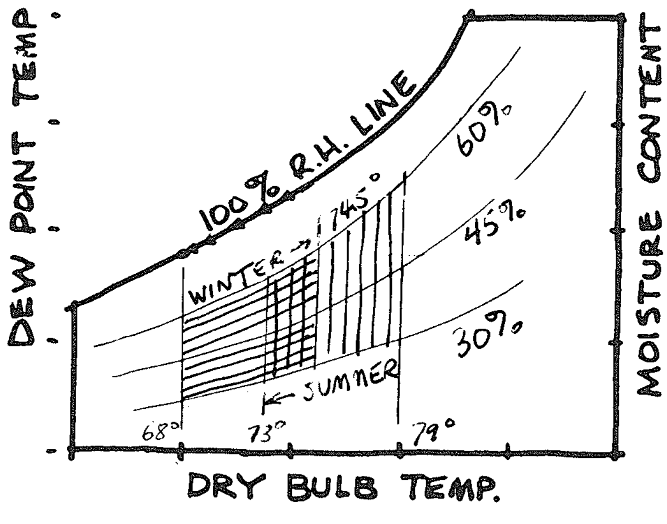
Temperature and humidity—for comfort

This standard was revised in 1992. The 1992 version specifies conditions in which 80% or more of the occupants should find the environment thermally acceptable. It does not address other environmental factors such as air quality, contaminants, and so forth.

Satisfaction with air temperature, humidity, and movement is a complex subject. This standard attempts to predict what conditions of temperature, humidity, activity, clothing, air movement, and radiant heat sources will satisfy 80% of the people.

The following figure summarizes the standard's provisions for temperature and humidity.

The figure is a simplified version of the original (which uses "operative temperatures" and concepts which can only be understood by reading the actual Standard. See Reference No. 2 for more information.)



In its simplest form, the Standard suggests that in winter, for people typically clothed, temperatures should range from 68-74.5°F. For summer, the temperature should be 73-79°F. These temperatures take into account some allowance for energy conservation (e.g., cooler in winter, warmer in summer.) Relative humidities should be maintained within the range 30-60%.

Answers to Exercises

Exercise 1. Turn now and review Checklist Nos 9-11. If you have access to a lab, write deficiencies below. (If you do not have access, consider a lab you are familiar with from the past.)

Who should you let know of these deficiencies?

Exercise 2. Does the Standard apply to laboratory operations? Explain the rational for your answer.

Yes, in most cases. However, when it is applied, the second approach, the Air Quality Procedure should be used. It is more compatible with traditional industrial hygiene procedures and control methods (e.g., control of sources, local and dilution ventilation). Indeed, Paragraphs 5.5 and 6.1 refer to local exhaust ventilation and the ACGIH *Ventilation Manual.* A conflict will exist when comparing the traditional TLV's/PEL's and ASHRAE's suggested approach of applying EPA Ambient Air Quality Standards (AAQS) to the indoor environment. When this situation arises, compliance with OSHA PEL's is necessary and attaining the restrictive AAQS's is perhaps a nice goal.

Exercise 3. Does the Standard require airflow monitoring of laboratory ventilation systems? If so, what techniques would be appropriate?

Yes, Paragraph 5.1 calls for airflow measurement and demonstrating adequate supply ventilation in all new buildings. Traditional approaches are acceptable (e.g., flow sensors, damper control sensors, static pressure sensors, and so forth. See Chapters 13 and 19 for more details.) Indeed, most HVAC systems installed in the last 20 years already have provisions for monitoring the performance of the air supply system. Exhaust systems may not be so equipped.

Exercise 4. How far away should a lab fume hood stack be placed from the intake for a building Air Handling system to preclude reentrainment of exhausted laboratory air?

For lab fume hood stacks a common value is "10 feet above and/or 50 feet away." Obviously, the distance must be tempered by the exhaust volume, contaminants, rates of emission, and so forth.

Intakes are better placed upwind of exhausts. It should be recognized that complete elimination of reentrainment is impossible. But when contaminants in exhaust air are diluted to acceptable concentrations (e.g., 1/100 of the exhaust concentration), reentrainment is not considered hazardous. See Chapter 15 for more information.

Exercise 5. Why has ASHRAE established a limit of 1000 ppm for carbon dioxide in indoor air? Does it apply in laboratories?

Carbon dioxide is used as a surrogate for other air contaminants which "naturally" exist (e.g., microorganisms, VOC's, and ETS.) People are the major source of carbon dioxide in the indoor environment. As the day wears on, the concentrations of carbon dioxide will increase. ASHRAE has determined that for most non-chemical operations (e.g., in *lab office spaces*), 15 cfm/person of outdoor air (OA) will keep background levels of carbon dioxide below 1000 ppm. (This approach is the *Ventilation Rate Procedure.*)

The standard *does* apply to laboratories. However, it is unlikely that carbon dioxide levels will rise much above background concentrations because of the high volumes of air moving through a lab equipped with an exhaust hood. The *Air Quality Procedure* should be used in laboratory spaces.

Exercise 6. A smoking lounge is to be installed in a small room of a large laboratory/office building. Approximately 3 people will be smoking at any one time, as a daily average. However, at lunch and at break times, as many as 10 persons may smoke. What amounts of OA should be supplied to the smoking lounge? What other provisions would be appropriate?

The Standard calls for 60 cfm/person OA in smoking lounges. On the daily average 3 x 60 = 180 cfm OA. However during breaks and lunch, 10 x 60 = 600 cfm OA. The exact "correct" approach is not specified in the Standard. However, it seems logical that 180 cfm will not be sufficient for the lunch and break periods. Perhaps a two speed system could be installed. Perhaps a time-weighted amount could be provided, calculated from use/time relationships. (For example, 6 hrs x 3 = 18 smoker-hrs; 2 hrs x 10 = 20 smoker-hrs; adding the smoker-hrs = 38 smoker-hrs; dividing by 8 = about 5 smoker-hrs, average; 5 x 60 = about 300 cfm OA as the average required.)

Other useful and appropriate provisions include (1) isolating the ventilation system from the rest of the building, and (2) providing direct exhaust of the smoke-contaminated air. Studies have shown that some AHUs may dilute tobacco smoke to acceptable concentrations in some office buildings, but there is little possibility of diluting the concentrated smoke likely to be generated in a smoking lounge.

Chapter 13.
Air supply and HVAC systems

Supply must balance exhaust

When we think of lab ventilation, we often concentrate on the lab hood and its exhaust system. But that only represents half of the system. Every cubic foot of air exhausted must be replaced. The replacement or makeup air is provided by a dedicated supply system, an air handling unit or system, or more commonly, by the building HVAC (Heating, Ventilating, and Air Conditioning) system.

This chapter provides an introduction to HVAC systems. These systems not only provide replacement air, but control air temperature, humidity, and quality.

HVAC

HVAC is the generic term for ventilating, heating, cooling, humidifying, dehumidifying, and cleaning air for comfort, safety, and health. HVAC also concerns itself with odor control and maintaining carbon dioxide levels at acceptable concentrations (to meet ASHRAE 55 comfort and ASHRAE 62 air quality standards.)

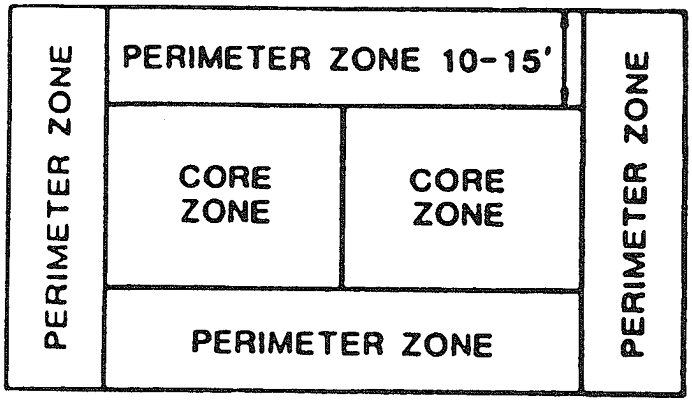
The 80% rule does not apply to health or safety considerations.

ASHRAE uses an 80/20 rule to establish satisfactory *comfort* performance. If eighty percent of the occupants are satisfied, then comfort requirements have been met. ASHRAE standards were introduced in Chapter 12.

We will concentrate on HVAC as it effects laboratory air supply problems and solutions. See **More Information** for general information on HVAC.

Each zone usually contains a thermostat to control temperature.

HVAC engineers talk in terms of "zones." The more zones there are, the better chance there is of providing satisfactory comfort conditions for more people. ASHRAE suggests that each lab or lab room should have its own thermostat. (2)



Many needs to satisfy

In designing a lab air handling supply system, the user must choose combinations of volume flow rate, pressure, temperature, humidity, and air quality which will satisfy the needs of the laboratory space. Lab air handling systems generally consist of:

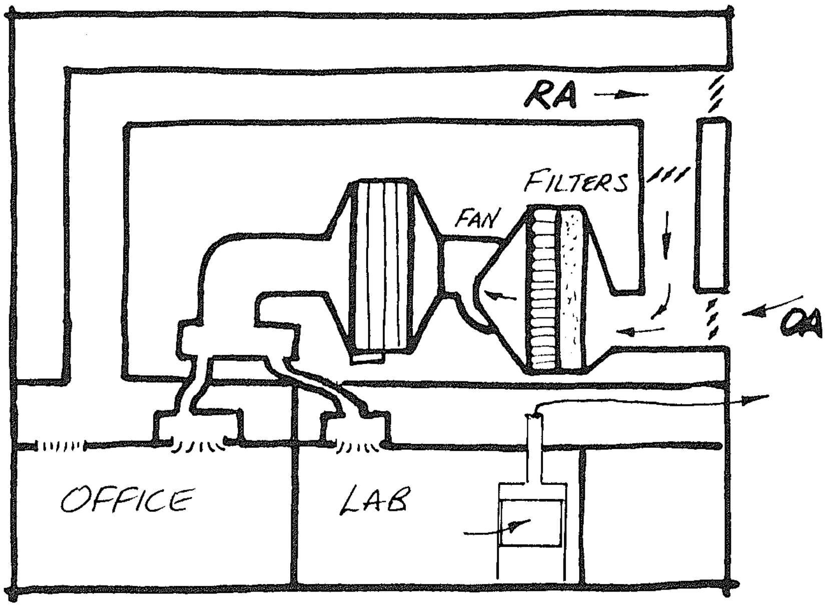
- Outside air plenums or ducts, OA
- Filters
- Supply fans
- Heating and/or cooling coils
- Humidifying or dehumidifying equipment

- Supply ducts
- Distribution ducts, boxes, plenums, and registers
- Dampers
- Return air plenums or ducts, RA (See note)
- Controls and instrumentation

RA systems are used ***only*** when certain restrictive conditions are met. See Chapter 12, ANSI Z9.5.

CV system

The next figure is a schematic of a simple, constant volume commercial HVAC system serving a laboratory. Systems vary in design and complexity, of course, but lets look at this one first.



OA

Every lab air supply HVAC system has an outdoor air *intake,* usually a louvered opening on the top or side of the building.

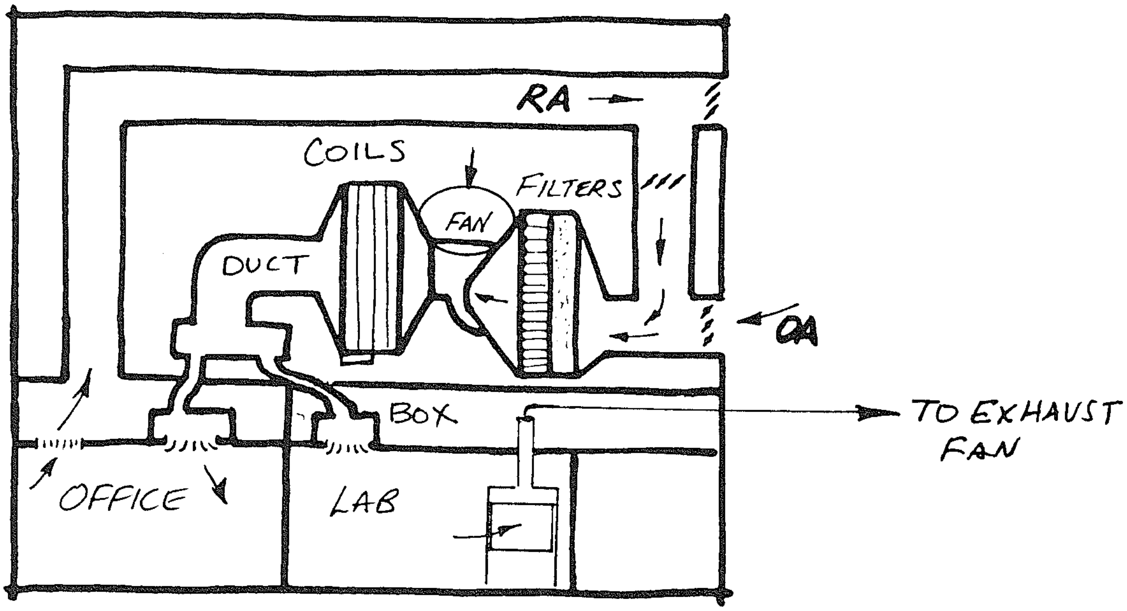
RA

Return air from non-laboratory spaces (e.g., offices, hallways, basement) may mix with the OA. Mixed OA+RA flows through filters. A prefilter or arrestance filter provides control of bees, flies, bird feathers, leaves, and larger dust. Small particles are separated from the air by a more efficient "dust spot" or HEPA filter.

Filter testing methods. ASHRAE supports the first two tests; DOE and ASTM support the HEPA filter test.

Filters can be rated by three tests. The first, called *arrestance,* measures a filter's ability to capture a coarse dust. The second, called *dust spot efficiency,* measures a filter's ability to control fine dusts. A DOP test can be used to test HEPA filters.

After the air flows through the filters, it enters a centrifugal *fan.*



Conditioning coils

Leaving the fan outlet, the air is pushed toward the coils. These coils heat and cool the air, depending on the temperature of the air and season. Winter air is typically heated to 68-73 degrees. Summer air may be cooled to 70-76 degrees. Leaving the coils, the air passes through a humidifier (or, dehumidifier) which brings the relative humidity to 40-60%.

Distribution network

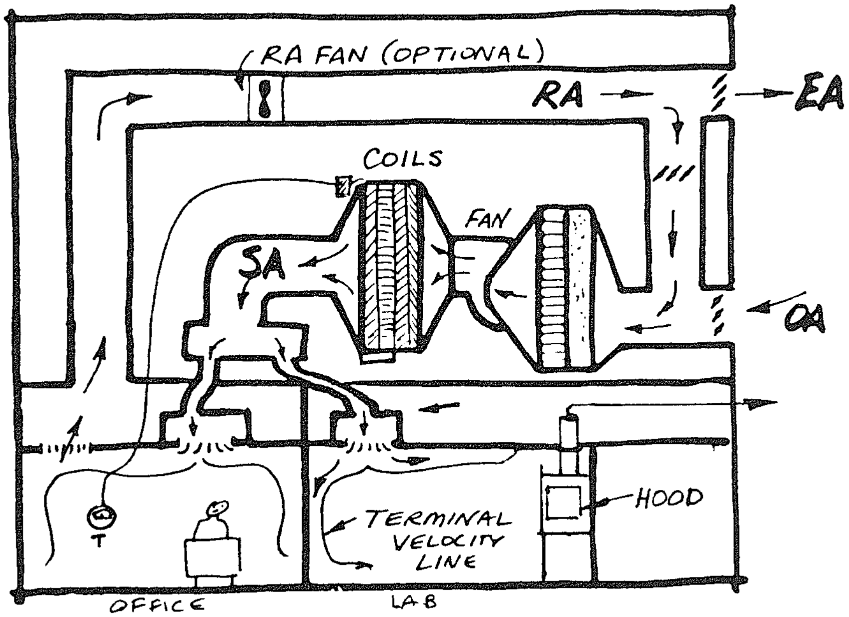
The air moves along metal ductwork at about 10-20 mph (1000-2000 fpm, typically) eventually reaching a distribution box. From there the air travels through smaller, flexible ducts to the supply terminals or diffusers in the lab ceiling or wall.

Use low velocity diffusers.

The (typically) large quantities of supply air should be introduced to the lab through perforated ceiling plates, or large-volume, low-velocity diffusers.

Keep terminal velocities well below 50 fpm.

Once in the room, the air typically hugs the ceiling and walls, and slows to a "terminal velocity" of about 40-50 fpm. The supply air should not blow on lab workers, or on the lab fume hood face until it is well below 50 fpm. Supply air should also not blow directly on fire, vapor or radioactivity detectors, either. (It slows their response time.)



Most supply air is exhausted from the lab fume hood

In a short time, the air migrates to the lab hood. From there the air is exhausted to the outdoors. Lab fume hood exhaust air should never be recirculated. HVAC air to laboratories should not be recirculated either, unless certain stiff requirements are met. (See ANSI Z9.5 standard on laboratory ventilation for details, Chapter 12.)

That's a basic, simple system, usually called a *single-*

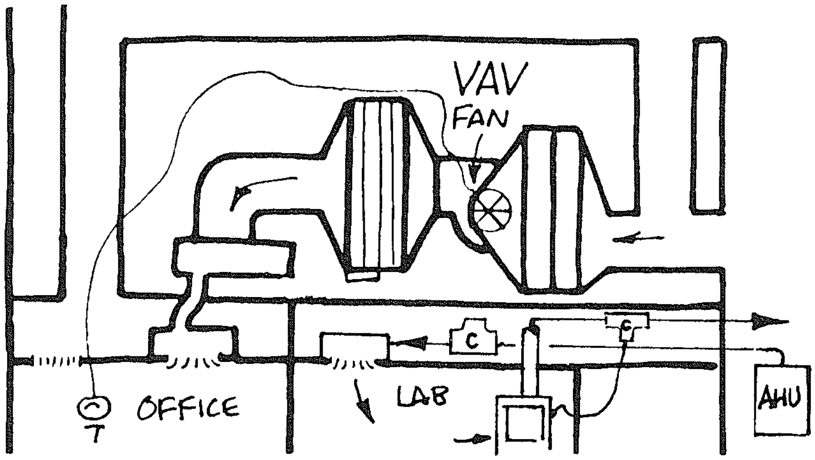
zone constant volume system. Lets look at a few modifications which add versatility and complexity to the system.

VAV systems must vary supply air as well as air exhausted.

The next figure shows a VAV [Variable Air Volume] system to control the amount of air exhausted. As the air in the lab fume hood is reduced, the amount of air being delivered to space is also reduced.

ASHRAE 62 calls for a minimum amount of OA, regardless of the amount exhausted.

The VAV system must be capable of delivering a minimum amount of air, even when the hood is not on. Bypass dampers in the ceiling may be used. [VAV systems require extensive instrumentation and sophisticated controls. Maintenance requirements and costs are high. Air balancing requires expertise and care.]



Pressure differences must also be maintained.

The *relative amounts* of exhaust and supply air must also be carefully controlled. Usually, a lab is kept under negative pressure with respect to adjacent hallways and offices. This minimizes the problem of odors traveling to adjacent spaces. To achieve this pressure difference, the supply air volume is usually less than the exhaust volume by 5-10%. The other 5-10% will be taken from the hallway or adjacent spaces.

Initial high costs and increased maintenance costs must be weighed against potential long term savings.

The advantage to variable air flow is energy conservation and lower operating costs. The largest savings are those associated with heating and cooling supply air. If the air flow rate can be cut in half, for example, a considerable savings is possible.

Exercise 1. What kind of air handling system serves the lab you are familiar with? Look into it and become familiar. Please use Checklist No. 11A, *Basic Information Checklist for Supply and HVAC systems*. Make notes below:

Checklists are primarily memory joggers, not training aids.

You probably couldn't understand everything on Checklist 11A. That points up the problem with checklists—they help us remember, but don't provide much in the way of information. This is also a good place to point out the obvious—HVAC is a complex subject requiring special education and experience.

Don't hesitate to admit inexperience, and to call for assistance!

The most *common* sources of trouble related to lab air supply systems are:

- Inadequate replacement of air exhausted
- The supply air blows on the face of the hood, reducing hood performance
- The large amount of supply air causes drafts in the lab
- There is poor distribution of supply air in the lab space; certain areas receive little air exchange
- Improper pressure differences—doors hard to open because not enough air is supplied to the lab
- Temperature extremes—too hot or too cold
- Humidity extremes—too dry or too humid
- Poor filtration—dirt, bugs, pollen in air delivery system

- Poor maintenance
- Energy conservation has become the No. 1 (or only) priority
- Improper balance
- Dampers at incorrect positions
- Supply terminal diffusers not at correct positions
- VAV systems not interconnected with lab fume hood exhaust systems
- contamination of supply air by odors from lab operations

Exercise 2. For each problem noted below:

A. Identify potential causes or sources associated with the following complaints or problems.

B. Suggest controls to remedy the problem.

Keep notes here:

1. The supply air system causes excessive drafts at the hood face.

2. The delivery of supply air to a laboratory is insufficient or non-existent.

3. There is cross-contamination within the building (e.g., chemicals used in a lab on the 3rd floor are detected in offices on the 5th.)

4. You find positive pressure in a lab that should be negative.

5. There is reentrainment of contaminants into the air handling system from hood exhaust stacks.

6. When the lab air is cool, the VAV system reduces delivery of replacement air so much that the room goes very negative.

7. You find high concentrations of carbon dioxide in an office adjacent to a laboratory.

8. Lab workers complain of tobacco smoke.

9. Lab workers complain of odors in the supply air.

10. Office workers near exterior walls complain of being too cold; in the interior of the building, lab workers complain of being too warm.

Case Study

Taking air for granted

(Adapted from the *IAQ and HVAC Workbook,* Reference No. 5.)

For your notes:

The San Macros File Corporation (a fictitious name) recently found itself in a dilemma. During the 1980's they became a major manufacturer of high quality files and rasps. In 1992 they built a new building near the factory, a two story structure. The building housed eight offices and two laboratories, and supported 22 people. Air conditioning was provided to the whole building. The HVAC system doubled as the replacement air system for the lab hood exhaust system—originally one hood in each lab.

In 1993, one of the lab techs called the Health Department about a recurring problem—"bad air in the building."

June visited the plant. She first met with a company vice president who then her escorted to the Plant Security Office. "Take care of this," the VP instructed the

Security Director. “Let’s cooperate fully.” JUNE finished the investigation in about an hour.

Returning to her office, June described the lack of makeup air in the building. “I could tell the minute I walked in. It was all I could do to pull the door open, there was so much negative pressure on it. Then when I saw the lab hoods, I knew we had a problem. I mentioned this to the security guy, who was kind of surprised. I guess he had never considered it.

Exercise 3. What do think is the problem?

“The security man called the A&E and the building maintenance guy. We all got on the phone together, the four of us. As it turns out, the A&E had designed the air handler to provide enough air to replace the air exhausted from two hoods. Then the maintenance man told us he put in two more hoods. Each exhausted 900 cfm. No one thought of increasing the air flow to the building! On top of that, somebody got the bright idea of closing off the outside air intake to save some money—seems the heating bills went up when the new hoods were installed. Cold air was infiltrating the outside walls because of the high negative pressure in the building. I was able to make some recommendations right on the spot.”

It wasn't long before two things had happened. The air handler was rebuilt to provide sufficient replacement for all the hoods. All duct systems were balanced to provide a slight negative pressure in the labs and a slight positive pressure in rest of the building.

June concluded the story. “You have to replace every cubic foot of air exhausted. That seems obvious, but most people are surprised. They just seem to take air entirely for granted.”

Answers to Exercises

Exercise 1. Use of a checklist helps to assure completeness.

Exercise 2.

1. The supply air system causes excessive drafts at the hood face.

Potential Problems: Diffuser too close to hood; diffuser louvers aimed at hood, high velocity diffuser installed.

Potential controls: Move diffuser, aim louvers away from hood, change diffuser to low velocity diffuser, use baffles on diffuser.

2. The delivery of supply air to a laboratory is insufficient or non-existent.

Potential problem: VAV control system not working properly, ductwork detached, dampers closed, fan belt broken, OA dampers closed.

Potential controls: Increase flow by adjusting dampers, rebalance, increase fan speed, modify systems or VAV controls, reattach ductwork, open OA dampers.

3. There is cross-contamination within the building (e.g., chemicals used in a lab on the 3rd floor are detected in offices on the 5th.)

Potential problem: Sources not controlled, pressure differentials, leakage at heat exchangers, changes in process exhaust systems, chimney effects, reentrainment from stacks to intakes.

Potential controls: Check hood containment of contaminants, rebalance HVAC systems, isolate lab areas (separate AHUs), fix leaking equipment, move chemicals out of building, provide makeup air, move stacks and/or intakes.

4. You find positive pressure in a lab that should be negative.

Potential problem: Lab hood installed with new makeup air system delivering more air than needed, systems out of balance, supply dampers closed (or exhaust dampers open), supply fan speed slowed, closed diffusers, VAV system not operating properly, adjacent labs under greater negative pressure.

Potential controls: Fix all of above.

5. There is reentrainment of contaminants into the air handling system from hood exhaust stacks.

Potential problem: Intake too close to exhaust stack, stacks not tall enough (10' minimum), building under negative pressure, chimney effect causes infiltration at lower levels of building.

Potential controls: Remove sources, raise stacks, move stacks, move intakes, balance systems.

6. A VAV system reduces delivery of air when the lab air is cold.

Potential problem: Poor design or improper application of VAV systems. This may occur when an office space is converted into laboratory space with a hood installed in the new "lab."

Potential controls: Set VAV to a fixed delivery, reformat system to deliver higher temperature air, provide reheat at distribution box, provide separate supply of air.

7. You find high concentrations of carbon dioxide in an office adjacent to a lab.

Potential problem: Insufficient OA, poor mixing, too many people for system, other sources of CO_2.

Potential controls: Provide more OA, improve distribution and mixing, use higher velocity diffusers, provide induction type diffusers, reduce people load, reduce or eliminate other sources.

8. Lab workers complain of tobacco smoke.

Potential problem: People smoking in labs. (Smoking should never be allowed in a lab.) Infiltration from adjacent spaces (e.g., smoking-permitted offices, smoking lounges).

Potential controls: Restrict smoking, provide separate air handler for designated smoking area.

9. Lab workers complain of musty odors.

Potential problem: Mold or slime in supply or HVAC air; recirculation of lab odors; exhaust from rooftop stacks reentrained into building air handling system.

Potential controls: Find and remove.

10. Near exterior walls office workers complain of being too cold; in the interior of the building lab workers complain of being too warm.

Potential problems: (1) Inadequate zoning, lab and office on same zone with thermostat in office. Cold air infiltrating at exterior of building cools air, calls for more heat. Interior of building (lab) overheats. (2) Air infiltration is caused by excessive negative pressure in building created by imbalance of lab exhaust and supply systems.

Potential controls: Rebalance systems, provide more zones to building, move thermostats, improve seals at exterior surfaces, provide sweaters. (Just kidding.)

Exercise 3. Read on.

Chapter 14
Reading plans and specifications

If you are involved with lab ventilation systems, you'll be expected to read *plans and specifications* from time to time.

A building consists of three basic systems: the structural (the steel or wood skeleton), the electrical (power, lighting, communications), and the mechanical (plumbing, piping, fire protection, and HVAC). Look for the mechanical plans and specifications.

New construction is usually based on plans developed by an "A&E" (Architect and/or Engineer) in accordance with the user's desires. Plans and specifications are prepared prior to construction.

Construction documents are the legal drawings, plans, and specifications from which a building is built or remodeled. Documents may include: working drawings (also, bid drawings) which outline the design intentions of the A&E, addenda and change orders, as-built drawings which show how the building was actually constructed, and O&M manuals for all mechanical equipment.

They all look extremely complicated. Actually, just the opposite is true. Yes, they are very detailed and busy, but they are also very simple when broken down to individual components. Drawings and specifications are written so the contractor or installer will know exactly what is expected. They are legal documents. "No detail overlooked" is the aim.

Most people review other's work.

Unfortunately, details are often overlooked and you may be asked to find them.

Almost all ventilation systems are built to recognized codes and standards. There are many recommended standards and some required regulations and codes.

Chapter 12 describes many of the more important standards and standards-setting organizations. Chart 2 summarizes some of the more important standards for exhaust ventilation work.

Plans and specifications usually follow standard forms and symbols described in the *Uniform Construction Index* (UCI), but they do differ from job to job.

Look for:
- Space (square footage, ceiling heights)
- Location of vent equipment (e.g., mechanical rooms)
- Types of equipment to be used (e.g., VAV)
- Occupancy (e.g., persons per room)
- Flow rates
- Zone boundaries and zoning techniques
- Duct locations
- Control strategy; types of control equipment; location of controls, instrumentation.

Plans and specifications usually go from the general to the specific. They are broken into sections: Electrical, Plumbing, Structural, *Mechanical,* and so forth. It is the *Mechanical* specs and drawings we concern ourselves with. UCI Section 15 is the section dealing with mechanical plans and specs. Paragraph 15A covers general information; Paragraph D covers HVAC and often includes specs for exhaust ventilation as well.

Exercise 1. You are asked to review the plans and specifications for a new hood to be installed in an existing lab. The proposed changes have been added to the original drawings for the lab. Where do you begin?

This is a sample specifications for a bypass lab fume hood. (See Reference No. 1 for additional information.)

Exercise 2. Review the specifications on this page. Would your own lab hoods meet these typical requirements? Do you have similar specifications in your files for the lab fume hoods in your facilities? Why not?

Typical Specifications for a Lab Fume Hood

1. The fume hood shall be of the "bypass" type. The air bypass shall be located above the hood face opening.
2. Bypass air shall pass through the work chamber of the hood.
3. The bypass shall provide a barrier.
4. The bypass mechanism shall provide a constant air flow rate through the hood at all times. Face velocities shall not increase more than three times the average with the sash at any position.
5. The hood shall have a vertical sliding sash.
6. The sash shall be counter balanced with stainless steel cables over ball-bearing pulleys with metal counter weights. The sash shall move freely throughout its range of motion and be capable of stopping at any point in its run.
7. When in the full-open position, the sash shall be at least 28 inches above the airfoil.
8. The fume hood shall be of the airfoil design type with a foil at the bottom and a taper along both vertical sides of the face opening.
9. The sash shall rest on the airfoil when in the down portion.
10. The bottom airfoil shall be raised approximately 1 inch above the bench surface.
11. The superstructure of the hood shall be counter-mounted.
12. Interior clear working height shall not be less than 36 inches above the work surface for the full depth.
13. The hood shall have a removable baffle with three slots, one near the bench surface, one in the middle, and one at the top.
14. Hood baffles shall provide a plenum. The plenum shall be provided with a round duct take-off flange of at least 10 inches, centered over the plenum.
15. Slots shall be fixed in place, but shall also be adjustable with common tools (e.g., screwdrivers, pliers, wrenches.)
16. All walls shall be of double construction and shall fully enclose structural supports, sash balance mechanisms, and mechanical connections for utilities and service outlets and controls.
17. Access shall be provided for the inspection and maintenance of the sliding sash mechanism and other mechanical services.
18. Materials of construction shall be non-flammable and acid resistant. Exterior surfaces shall be coated with baked enamel.
19. The hood shall be exhausted so as to provide an average velocity of 100 fpm through the face of the hood when the sash is in the wide open position. The velocity across the face shall be uniform, and shall not exceed plus or minus 10 percent of the average at any one position when tested at the manufacturer's plant, and plus or minus 20% at the installed location.
20. The hood shall be capable of meeting an ASHRAE 110 test rating of 4 AM 0.01.
21. The manufacturer shall provide written and documented results of all tests at the time of delivery.
22. Non-flammable chemical storage shall be provided in a base cabinet constructed so as to be compatible with the hood.

Exercise 3. Review **Checklist No. 12.** Would you ever be asked to review a set of plans or specifications? Are your ready?

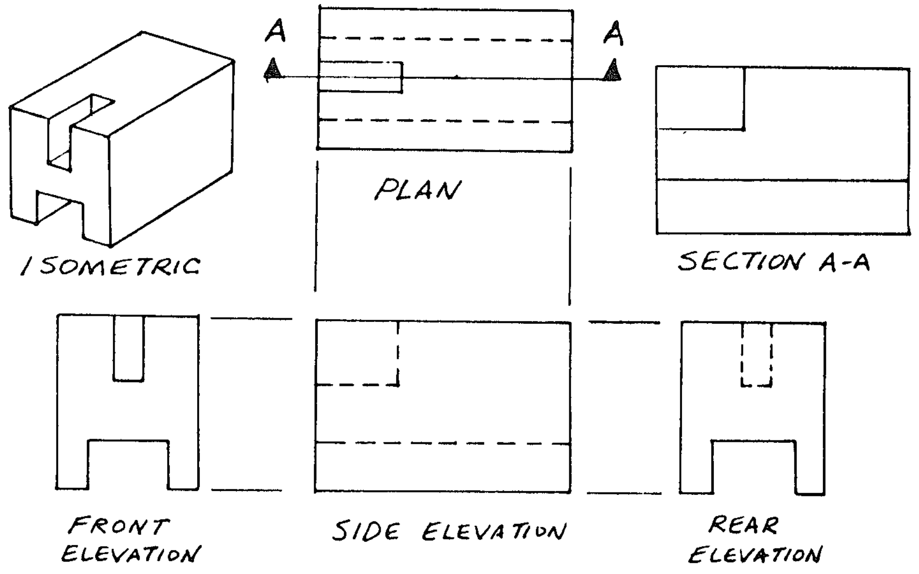
"Drawn to scale"

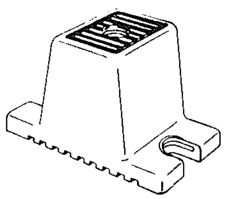
Drawings are usually drafted to scale. For example, 1/8" on the sheet may represent one foot on the ground. With a ruler, or a scale, you can check dimensions and lengths.

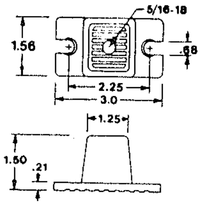
Types

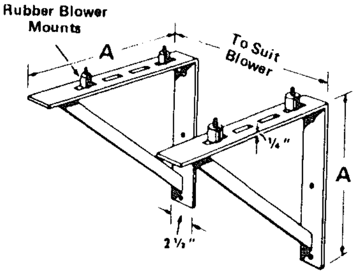
Drawings come in many types and views: *plan* (top), *elevation* (side and front), *isometric, section,* and so forth.

A plan view shows how it looks from above. An elevation drawing (side and front views), give more detail. An isometric drawing is one that looks three dimensional. A sectional drawing provides detail by slicing through the drawing at the section line and turning it 90-degrees so we can see the cross-section.









Most drawings follow standard symbols. See Reference No. 4 for examples.

Exercise 4. The pages at the end of this chapter present typical drawings. Study the drawings and become familiar with the project.

Understanding requires careful attention to every detail. An old saying: "Reading plans and specifications gives knowledge; not reading gives experience."

Any notes:

Case Study

The Dragon Killer

"I don't usually review plans and specifications," June said. "But this was my friend Carol at the College. We went to school together a thousand years ago. She's like me, a nurse turned into an environmental nerd."

The group in June's office laughed. June was definitely the antithesis of a nerd.

The local college had been building a new wing on its chemistry department. A demonstration lab was to be built with four new fume hoods. June had spoken with Carol at some length about the project in order to prepare herself for the review.

Exercise 5. What do think should be done to prepare to review plans and specifications?

"It was a straight-forward job," June continued. "No complicated VAV systems or fancy controls—just four conventional hoods attached to a duct which ran to a fan on the roof. I told Carol I'd give it a look."

The plans and specifications had been delivered to June's office three days later. The first thing she had seen was the notice stamped on the roll of drawings: **95% Completion** . "That made me nervous," June said. "Nobody wants to get negative comments when the design project is almost finished. Carol should have sent the plans over at the 30% or 50% completion level."

In reviewing the specifications, June had noticed that there was no reference to NFPA 45, ANSI Z9, or to the *ACGIH Manual.* "That got me wondering what design standards might have been followed, if any."

It was difficult for June to follow all the intentions of the designers. None of the calculations were provided, of course. If June wanted to see what kind of face velocities were intended in the hood, she was forced to back-calculate using the specified fan volume flow rate and the product literature for the hoods. "Face velocities looked suspicious," June said. "With the sash up, the face velocities in the hood were going to be only about 50 fpm, at best. That's about half of what I'd consider reasonable for a college lab hood."

June called Carol about the face velocities. Carol explained that it was intended that only two hoods be operated at any one time (the other two would have their sash completely closed), or that all the hoods would have all of their sashes lowered to the half-way point during operation. "I told Carol that that was pretty optimistic—college students following rules like that. I told her that it also didn't meet good accepted practice anymore. Lab hoods should be designed to operate with the sash up." June looked disgruntled. "What is this, the dark ages?" she muttered, then smiled.

"Anyway, that wasn't the main problem, it turns out," she continued. I got looking at the drawings and noticed that no straight ductwork connected the fan with the incoming elbow. I made a few calculations and determined that the fan specified for the system would experience a considerable reduction in performance due to the *system effect loss* at the fan inlet. I called Carol again, and told her there was real trouble this time. She said she'd have the Project Manager call me."

The project manager called June the next day. He listened skeptically, then told June that one of the most prominent architects in the city was designing the system. "The PM told me he couldn't see how they could have made such an obvious mistake. I told the PM that system effect losses weren't that well understood. He told me he'd check it out. I didn't hear from anybody for a couple of days."

Two days later, June was asked to join a conference call with the Project Manager, Carol, and the architect. It was quite a conversation, with Carol finally convincing the architect. "I felt sorry for the gentleman," Carol said, with genuine concern. "He got caught like so many others."

"So, what happened?" Ted asked.

"Well, it wasn't all bad," June said. "In order to overcome the system effect loss, the fan had to be moved. That caused a problem with the structural-something and they had to redesign the roof. They also decided to upgrade the system so that all the hoods could run with the sash wide open. And they went to bypass hoods—certainly an improvement over the original plan."

"Sounds like your review really helped," Ted observed.

"Yes, it sometimes can do some good," June said. "But it puts a lot of responsibility on the reviewer."

Answers to Exercises

Exercise 1. You are asked to review the plans and specifications for a new hood to be installed in an existing lab. The proposed changes have been added to the original drawings for the lab. Where do you begin?

Look over the preliminary information, usually at the front, which covers general information (objectives, scope, location, and so forth.) Look also through the drawings for those numbered "M-1, M-2", and so forth. These are the mechanical drawings, which show plumbing, ductwork, and other mechanical aspects of the project.

Exercise 2. Review the specifications on the previous page. Would your own lab hoods meet these typical specifications? Do you have similar specifications in your files for the lab fume hoods in your facilities? Why not?

Unfortunately, many jobs do not have adequate planning.

Exercise 3. Review Checklist No. 12. Would you ever be called upon to review a set of plans or specifications?

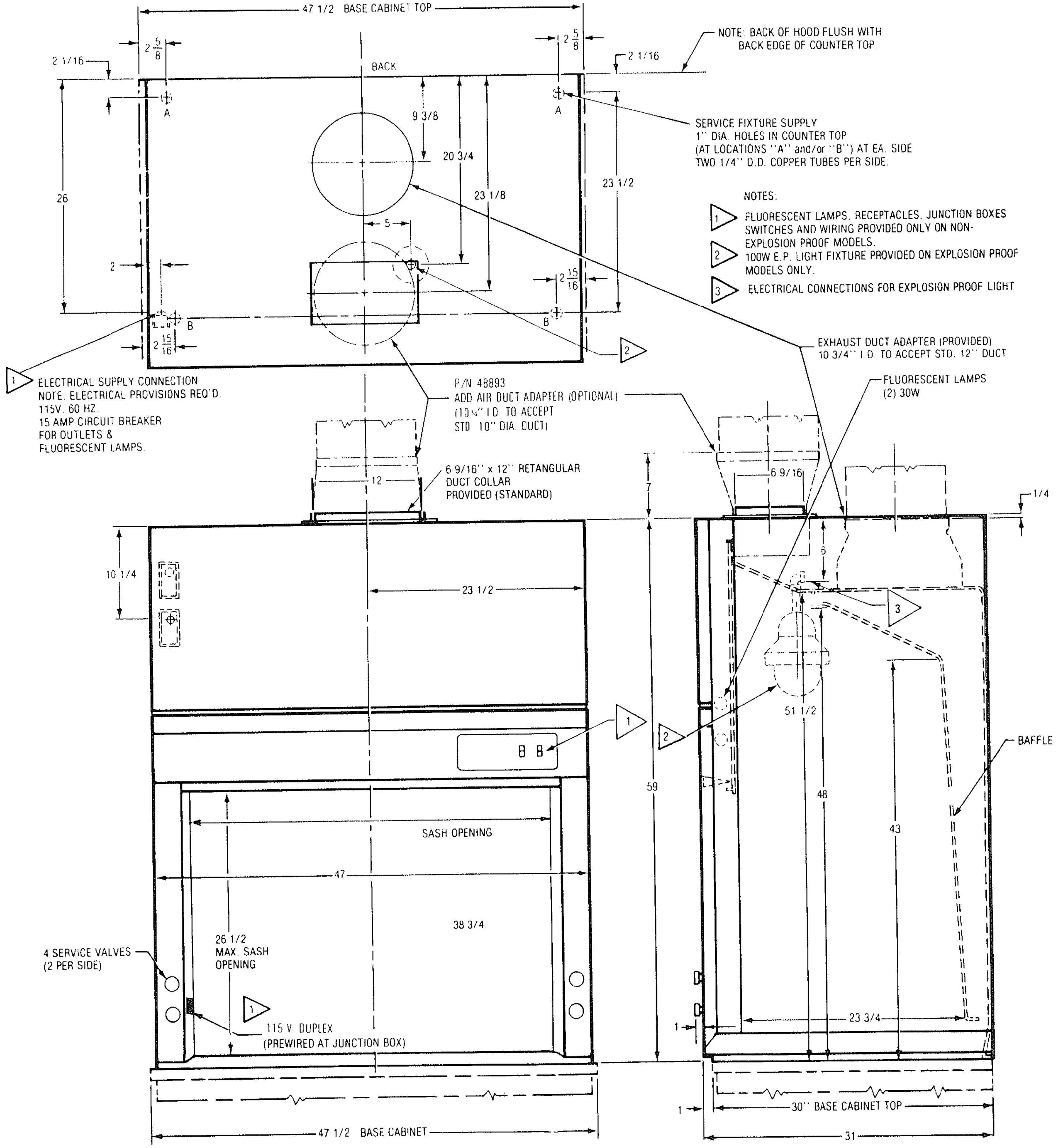
Sometime in your career you will. This checklist can be of value then.

Exercise 4. Study the drawings and become familiar with the project.

It takes time. Sometimes we are unfairly asked to review in an hour drawings which may have taken six months to prepare. Insist on time.

Exercise 5. What do think should be done to prepare to review plans and specifications? June would probably want to:

- investigate the background and objectives of the project, and
- understand the scope of the project. What is to be included and why? Who will use the equipment? What kind of chemicals are to be used? What standards are to be met?



NOTE: BACK OF HOOD FLUSH WITH BACK EDGE OF COUNTER TOP.

SERVICE FIXTURE SUPPLY
1'' DIA. HOLES IN COUNTER TOP
(AT LOCATIONS ''A'' and/or ''B'') AT EA. SIDE
TWO 1/4'' O.D. COPPER TUBES PER SIDE.

NOTES:

1. FLUORESCENT LAMPS. RECEPTACLES. JUNCTION BOXES SWITCHES AND WIRING PROVIDED ONLY ON NON-EXPLOSION PROOF MODELS.
2. 100W E.P. LIGHT FIXTURE PROVIDED ON EXPLOSION PROOF MODELS ONLY.
3. ELECTRICAL CONNECTIONS FOR EXPLOSION PROOF LIGHT

EXHAUST DUCT ADAPTER (PROVIDED)
10 3/4'' I.D. TO ACCEPT STD. 12'' DUCT

FLUORESCENT LAMPS
(2) 30W

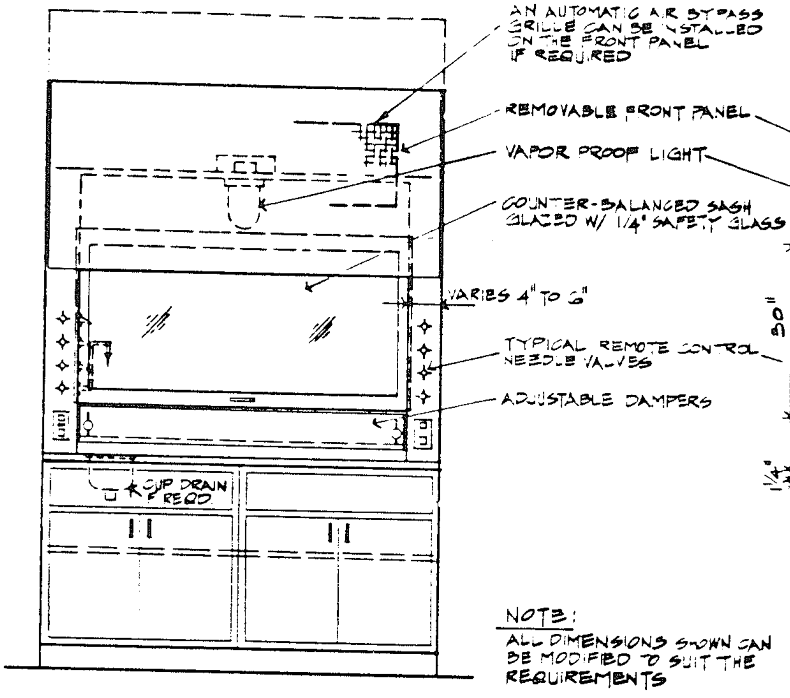
1 ELECTRICAL SUPPLY CONNECTION
NOTE: ELECTRICAL PROVISIONS REQ'D.
115V. 60 HZ.
15 AMP CIRCUIT BREAKER
FOR OUTLETS &
FLUORESCENT LAMPS.

P/N 48893
ADD AIR DUCT ADAPTER (OPTIONAL)
(10¼'' I D TO ACCEPT
STD 10'' DIA. DUCT)

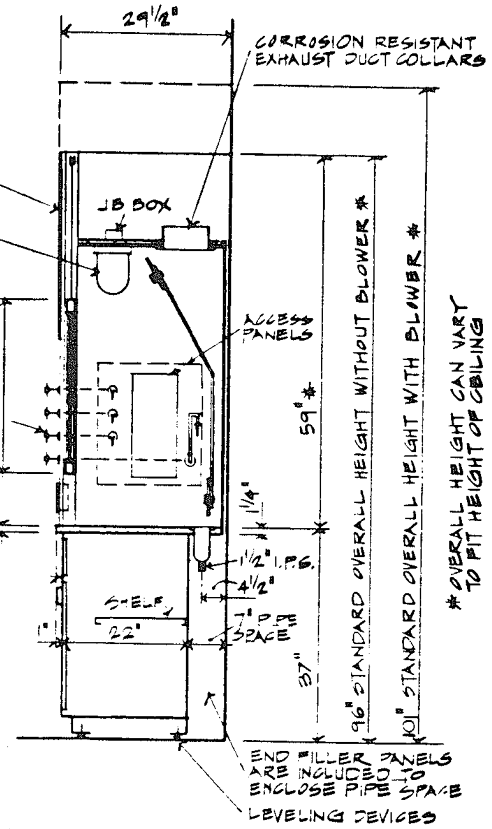
6 9/16'' x 12'' RETANGULAR
DUCT COLLAR
PROVIDED (STANDARD)

4 SERVICE VALVES
(2 PER SIDE)

115 V DUPLEX
(PREWIRED AT JUNCTION BOX)


AN AUTOMATIC AIR BYPASS GRILLE CAN BE INSTALLED ON THE FRONT PANEL IF REQUIRED
REMOVABLE FRONT PANEL
VAPOR PROOF LIGHT
COUNTER-BALANCED SASH GLAZED W/ 1/4" SAFETY GLASS
VARIES 4" TO 6"
TYPICAL REMOTE CONTROL NEEDLE VALVES
ADJUSTABLE DAMPERS
CUP DRAIN IF REQD
NOTE:
ALL DIMENSIONS SHOWN CAN BE MODIFIED TO SUIT THE REQUIREMENTS

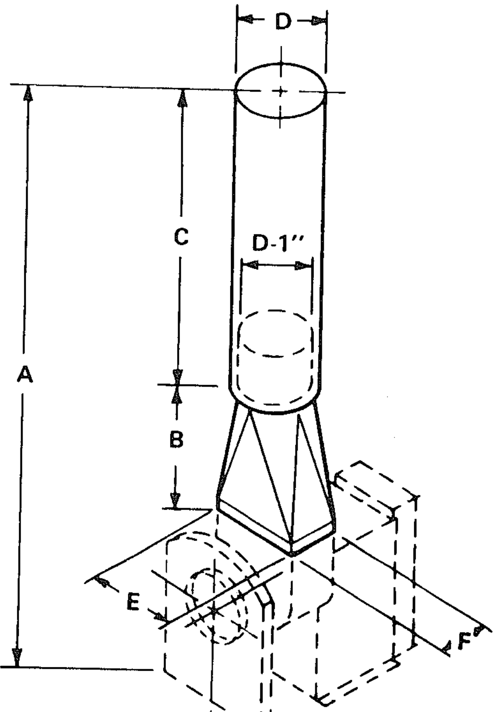
TYPICAL FRONT ELEVATION


29 1/2"
CORROSION RESISTANT EXHAUST DUCT COLLARS
JB BOX
ACCESS PANELS
30"
59"*
1/4"
1 1/4"
1 1/2" I.P.S.
4 1/2"
SHELF
22"
1"
7" PIPE SPACE
37"
96" STANDARD OVERALL HEIGHT WITHOUT BLOWER *
101" STANDARD OVERALL HEIGHT WITH BLOWER *
* OVERALL HEIGHT CAN VARY TO FIT HEIGHT OF CEILING
END FILLER PANELS ARE INCLUDED TO ENCLOSE PIPE SPACE
LEVELING DEVICES

TYPICAL VERTICAL SECTION

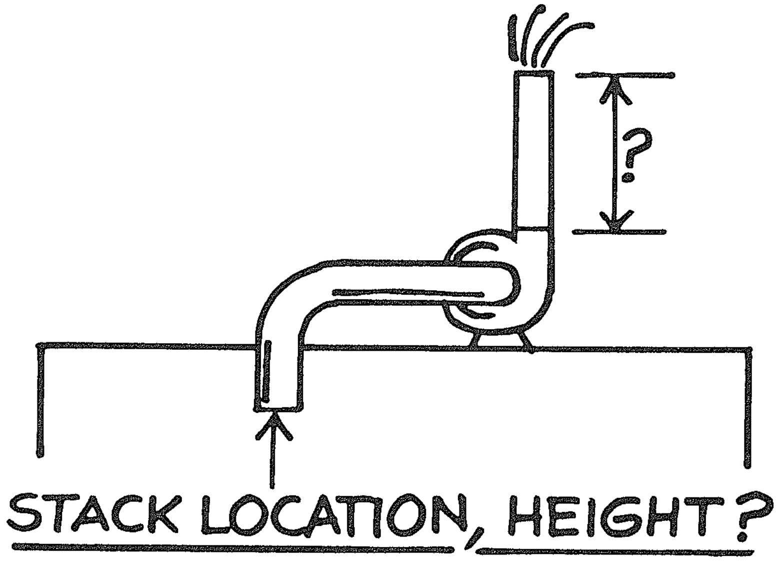
A	B	C	D	E	F	G
76⅞″	14″	42″	9″	7⅞″	5⅜″	8″
83⅛″	16″	46″	10″	9³⁄₁₆″	6½″	9″
88 1⁄16″	16″	50″	11″	10¾″	8″	10″
105½″	16″	62″	14″	13¼″	9⅝″	13″
112⅜″	18″	66″	15″	14⅜″	10¾″	14″
121¾″	18″	74″	17″	16¼″	11¾″	16″

E & F are exhaust outlet of blower.



Chapter 15.

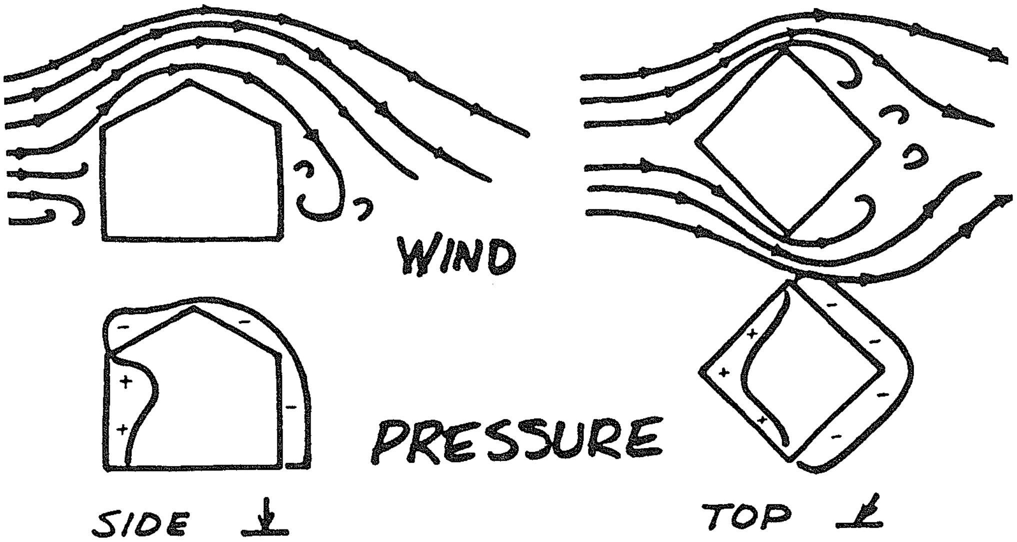
Placement of stacks, exhausts and intakes



The placement of laboratory hood ventilation stacks should minimize reentrainment. However, complete isolation is impossible. It has been estimated that even under ideal conditions, 1% of the exhausted air will be reentrained into the building. The reentry occurs at HVAC intakes, at makeup air units, or by infiltration along building walls.

Pressures exist all around a building

As wind blows around a building, it creates positive and negative pressures on the building surfaces.



Outside surfaces under positive pressure will experience infiltration through openings in the surface. Surfaces under negative pressure will experience exfiltration.

Location of HVAC exhausts and intakes

D. J. Wilson has suggested that building air intakes should be placed on the lower one-third of a building and the HVAC exhaust on the upper two-thirds or on the roof. Intakes should not be placed near the ground, loading docks, or busy streets. (2,9)

Exhausts should preferably be placed on the predominant downwind side of the building, and intakes on the upwind side. When exhausts are located on the roof, esthetics enclosures should be discouraged. If required, they should be of the open-louvered type, which allows horizontal winds to flush the enclosure. Air intakes should not be located within the enclosure.

Exit velocities for HVAC exhausts should be designed to exceed twice the wind speed. The average wind speed in the USA is 8 mph, so design for exit velocities =15 mph (about 1300 fpm), or greater.

Avoid the use of rain caps on stacks. They tend to direct the flow of exhaust air back toward the roof. Such caps can greatly reduce the dilution of exhausted air. (2,9)

Lab hood exhaust stacks

A lab hood exhaust stack disperses contaminants generated in the hood. Unfortunately, some (e.g., one percent or more) is likely to be reentrained into the building. Good design attempts to minimize this problem.

Mostly air

The exhaust gas from a lab hood usually consists almost entirely of air and a small amount of chemical contaminant (e.g., concentrations of gas or vapor in a typical lab fume hood rarely exceed 100 parts per million.) The exhaust air temperature is close to room temperature. After the exhaust air leaves the stack it is further diluted and dispersed.

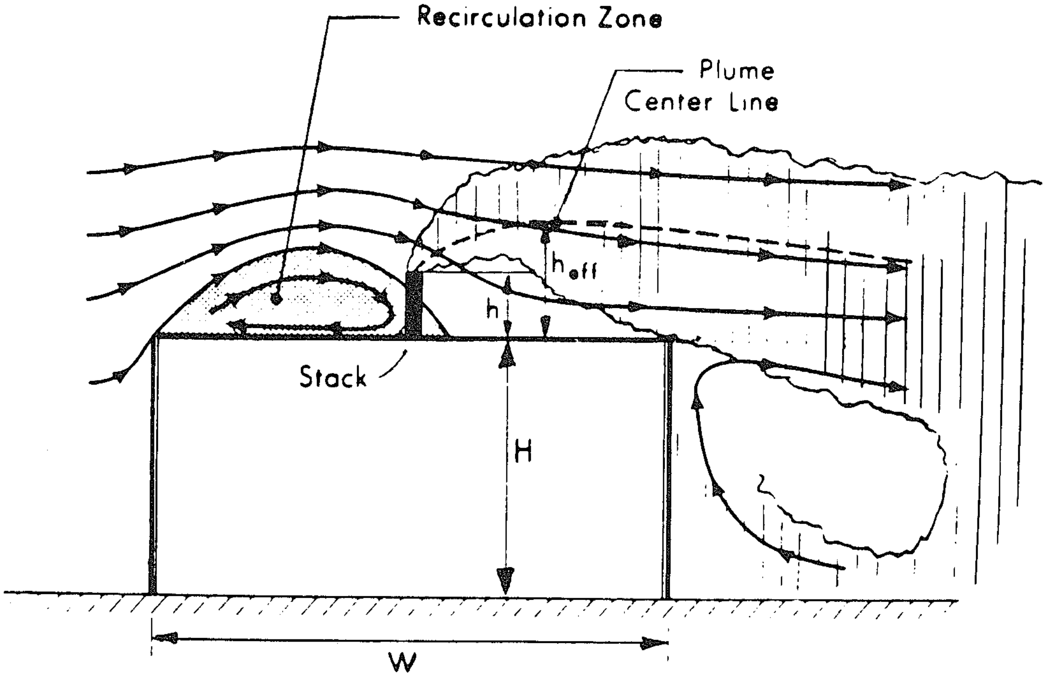
Large dilution factors

The amount of dilution is proportional to the wind speed and the square of the distance away, and inversely proportional to the exhaust volume flow rate and the initial concentration in the exhaust air. At a distance of fifty feet, and at *minimal* dilution, air exhausted from a hood at Q = 1000 cubic feet per minute (cfm) will usually be diluted by a factor of 100X or more. In more favorable conditions (e.g., greater wind speed, different wind direction, higher effective stack height) the dilution factor will be higher.

Avoid downturning raincaps

The use of rain caps may significantly reduce the dilution factor, however.

Unfortunately, it is very difficult to accurately predict the behavior of air after it leaves a stack, but a few expected trends are worth mentioning. The next figure shows a typical example of the distribution of an exhaust plume from a stack on a roof. In the figure, H is the building height, W is the building width parallel to air flow, h is the stack height, and $h_{(eff)}$ is the effective stack height.



"Effective" stack height

The effective stack height depends on the stack velocity and the exhaust air temperature. Generally, the more stack velocity and temperature exceed wind velocity and ambient temperature, the higher the effective height $h_{(eff)}$ of the stack.

The plume rise due to momentum and buoyancy does not continue indefinitely, but usually levels off rather quickly and at heights not much higher than the stack itself.

Mathematical models are available to predict stack effective height, but are beyond the scope of this *Workbook.* It is safe to assume, however, that you cannot add much more than about 5-10 feet to the actual stack height, h.

Good practices:

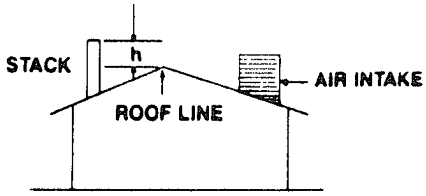
The following good practices are generally accepted among designers of stacks and air handling equipment:

Avoid cavity

- Place the stack to avoid exhausting into the "recirculation cavity." (See the last figure.) Many designers feel 10 feet will provide enough height to breach the recirculation cavity on most roofs.

“10 and 50 rule”

- Provide ample stack height, h. A good rule of thumb says stacks within fifty feet of the roof line or air intakes should be h = 10 feet tall.



h 10' ABOVE ADJACENT ROOF LINE AND/OR AIR INTAKE WITHIN 50' OF STACK.

- In no case should stacks be less than 7 feet. (This is the minimum height required by NFPA 45.) This height is intended to protect maintenance people working near the stack.

- Some designers use an older (and some say out-dated) rule of 1.5 X the building height, or

  h+H = 1.5H (See the last figure.)

  For example, if a one story building is 14 feet high, the stack would be 7 feet tall. This rule is useful only for buildings 1-3 stories tall, obviously. For tall buildings, it is sometimes acceptable to use H = 0.5W as the building height, so h+H = 0.75W.

- Place the stack downwind of building air intakes.This suggestion is limited because wind speed and direction vary from hour to hour, day to day, and season to season. When there is no significant prevailing wind, then the following suggestions take on greater importance.

Downwind of intakes if possible; if not, use "10 and 50 rule."

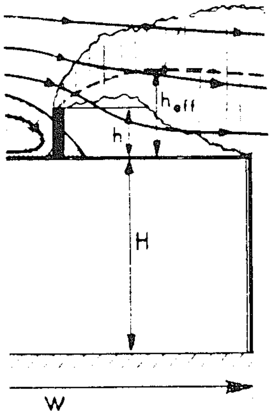
Exit velocities should be 3,000 fpm or higher.

- Provide a stack velocity 1.4X the wind velocity. This is usually sufficient to avoid "downwash" around the stack and to avoid reverse flow down the stack from wind pressure. It also supplies additional "effective" stack height, $h_{(eff)}$. Many designers specify stacks for a twenty-five mile per hour wind which results in a stack velocity of about 3,000 feet per minute.

- Place the stack as far away as possible from any air intake. Fifty feet is considered adequate in most cases.

- Avoid rain caps if the building air handling intake is within 50 ft. These turn the plume back down onto the roof, minimizing effective stack height.

Example 1. A lab fume hood stack is located on the roof of a two-story building. The average wind speed is 8 mph and the predominant wind is out of the south. Where should the stack be located? How tall should the stack be? What stack exit velocity would be appropriate?



If possible, the stack should be on the north end of the building, 50 feet from any air intake, and at least ten feet tall with a stack exit velocity of 3000 fpm. (The average wind speed is irrelevant.) If the older equation is used:

$h+H = 1.5H = 1.5\ (20') = 30'$ (where $H = 20'$, about the height of a two story building)

and

$h = 30 - H = 30' - 20' = 10'$ (where h = height of stack)

Exercise 1. A lab fume hood stack is located on the roof of a five-story building. The building is about 80 feet wide, north to south. The maximum wind speed is about 25 mph and the predominant wind is out of the north. Where should the stack be located? How tall should the stack be? What stack exit velocity would be appropriate?

Answers to Exercises

Exercise 1. A lab fume hood stack is located on the roof of a five-story building. The building is about 80 feet wide, north to south. The maximum wind speed is about 25 mph and the predominant wind is out of the north. Where should the stack be located? How tall should the stack be? What stack exit velocity would be appropriate?

If possible, the stack should be on the south end of the building and 50 feet from any air intake, and at least ten feet tall with a stack exit velocity of 3000 fpm. If the older equation is used:

Don't use this approach. (For calculation purposes only.)

h+H = 1.5H = 1.5 (50') = 75 feet (where H = 50 feet, about the height of a five story building)

and

h = 75' - H = 75' - 50' = 25 feet (where h = height of stack)

Obviously this is too tall for practical use. As mentioned in the text, this older formula is useful only for one- to three-story buildings.

For taller buildings, it is sometimes acceptable to use $H = 0.5W$ as the building height, so $h + H = 0.75W$.

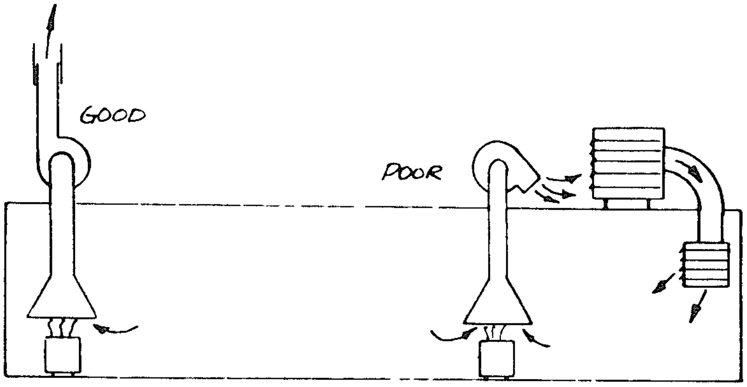
Therefore,

$H = 0.5 \times 80' = 40$ feet and

$h + H = 0.75W = 0.75' \times 80' = 60$ feet and

$h = 60' - 40' = 20$ feet

Still too tall for practical use. In this case, the "10 and 50" rule seems more acceptable.



Chapter 16. Dilution equations for laboratories

General Dilution Ventilation in Labs

Dilution ventilation is also known as “general exhaust.”

Most laboratory operations are conducted in hoods. But much bench work remains. These bench activities invariably produce odors or the potential for exposure.

Lab fume hoods are generally successful in controlling emissions of chemical contaminants. However, no hood provides complete containment.

In order to protect lab workers, fugitive emissions from hoods and bench operations should be diluted to acceptable concentrations. The greater the toxicity of materials used in the lab, the greater the need for dilution ventilation.

[Replacement air doubles as dilution air.]

Fortunately, labs equipped with fume hoods have a dilution system built in. Often, the amount of dilution air is large.

Example 1. Two bypass-type lab fume hoods exhaust a total of 2,400 cubic feet per minute. Makeup air is provided by the HVAC system. The hoods run all day long in a lab of dimensions 15'x 20'x8'.

What is the dilution volume flow rate? The number of air changes per hour in the lab?

The dilution ventilation volume flow rate must equal the exhaust rate. (Every cubic foot *must* be replaced.)

The number of air changes per hour (ac/hr) is given by

$$N = \frac{Q \bullet 60}{Vol} \quad \left(= \frac{Q \bullet 3600}{Vol}, \text{ metric units}\right)$$

where

N = number of air changes per hour, ac/hr
Q = the volume flow rate of air, cfm (cu m/sec)
Vol = the space volume, cubic feet (cubic meters)

$$N = \frac{Q \bullet 60}{Vol} = \frac{2400 \bullet 60}{15 \bullet 20 \bullet 8} = 60 \text{ ac/hr}$$

Exercise 1. A constant volume lab fume hood exhausts a total of 1,150 cubic feet per minute. Makeup air is provided by the HVAC system. The hood runs all day long in a lab of dimensions 12'x18'x9'.

What is the dilution volume flow rate? The number of air changes per hour in the lab?

A large number indeed. In this lab, enough air is supplied to dilute most fugitive emissions if the dilution air is distributed adequately.

Where lab fumes hoods are not used, dilution air must be supplied to meet standards (e.g., ASHRAE 62-1898) and to keep contaminants at acceptable concentrations in the lab space.

Acceptable exposure concentrations in the breathing zone (BZ)

In the dilution control approach, contaminated air is diluted to *acceptable* exposure levels. This safe or comfortable level of exposure is called (naturally) the *Acceptable Concentration, C_A* (e.g., carbon dioxide at C_A =1000 ppm).

Conditions conducive to the use of dilution ventilation as a primary control

Certain conditions seem to suggest dilution ventilation as a primary ventilation control strategy. The following list suggests important considerations.

- Lab work is not conducted in lab fume hoods
- Air contaminants are not hazardous
- Air contaminants are primarily vapors or gases, or respirable sized aerosols

- Emissions occur uniformly in time
- Emission sources are widely dispersed
- Emissions do not occur close to people
- Moderate climatic conditions prevail
- The outside air is not more contaminated than the inside air

Economics always plays a major role

When the last seven conditions are not present, the volume of dilution ventilation will be high, thus raising operating and heating costs. In this case, lab hoods, other local exhaust systems, emission reduction, or other forms of control should be considered.

Indoor lab air is almost always more contaminated than outdoor air

In the majority of cases, the outdoor air will be less contaminated than indoor air. Outdoor concentrations of the reactive gases sulfur dioxide and ozone are usually greater than indoor concentrations. However VOCs, carbon dioxide, formaldehyde, ETS particle concentrations are almost always greater indoors than outdoors. Any chemical used in a lab will almost always create greater concentrations in the lab than outdoors.

Exercise 2. Lab workers are complaining about "poor ventilation." Specific complaints include headache, watery eyes, irritation of the nose and throat, and dry, itchy skin. The lab uses a variety of solvents and other organic chemicals. Most of the chemical operations are conducted in lab fume hoods, but some are conducted on open benches. Would additional dilution ventilation be appropriate? What information should you gather to decide?

Check the literature for more information

Exercise 2 suggests that dilution ventilation may not be as important as other forms of control in laboratories. For more in-depth information on the application and use of dilution ventilation (e.g., in offices), please see the *IV* or the *IAQ /HVAC Workbooks.* (Ref 4,5)

Estimating gas and vapor concentrations in fume hood exhaust air

Please follow this procedure carefully.

The traditional dilution ventilation equations can be used to estimate the concentrations of gases and vapors in lab fume hoods. This can help us determine an existing hood's effectiveness, or the required performance of a hood to be purchased. A step-by-step procedure is provided below:

Emission characterizations

1. Develop a thorough understanding of emission sources; gather the following information:

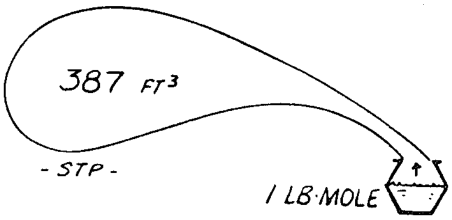
    - Descriptions of emission sources in the hood.
    - Chemical description of emissions to include chemical composition, size and shape, and temperature.
    - Rates of usage or evaporation over time.
    - Amount of chemical emitted or evaporated into hood exhaust air.

The most intimidating of these is the last item. Estimating consumption rates for contaminants requires ingenuity, detective work, and skill. But it can be done.

Start at the beginning. "How much of this do you use a day?" Where does the lost material go? Into the hood exhaust air? Into the lab air? Down the drain? Into the chemical process?

Estimate emission rate

2. Once you have an estimate of the amount emitted to the hood exhaust air, estimate an emission rate for liquids:



$$q = \frac{387 \bullet \text{lbs evaporated}}{\text{MW} \bullet \text{minutes}} \quad \left(= \frac{0.0244 \bullet \text{grams}}{\text{MW} \bullet \text{Seconds}} \right)$$

where

q = volume of vapor flow rate in scfm, at STP (m^3/sec, metric)
MW = molecular weight
lbs = amount emitted to exhaust air, in lbs (grams)

3. Estimate the volume of air required to dilute a volume of vapor. The formula is given by:

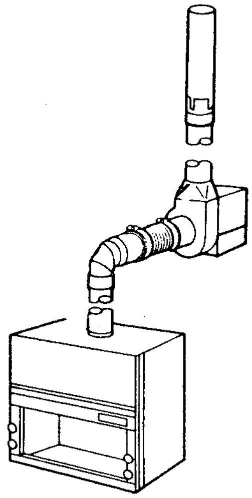
$$Qd = \frac{q \bullet k_{(mixing)} \bullet 10^6}{C_{ex\ (ppm)}}$$

and, transposing

$$C_{ex\ (ppm)} = \frac{q \bullet k_{(mixing)} \bullet 10^6}{Qd}$$

where

Qd = volume flow rate of dilution air, scfm (cu m/sec)
q = volume flow rate of vapor, scfm (cu m/sec)
C_{ex} = the concentration in the exhaust air, ppm
$k_{(mixing)}$ = a mixing factor to account for incomplete or poor mixing.



The value of $k_{(mixing)}$ can be assumed to be one. (We assume perfect mixing in the exhaust air, a reasonable assumption.)

Example 2 What is q, the volume flow rate of vapor formed, if 0.25 pounds of toluene are evaporated in a lab fume hood during an 1-hr period? What volume flow rate Qd is required for dilution to Cex =10 ppm, if $k_{(mixing)}$= 1? (STP, MW = 92.1)

$$q = \frac{387 \bullet \text{lbs evaporated}}{\text{MW} \bullet \text{minutes}}$$

$$q = \frac{387 \bullet 0.25 \text{ lbs evaporated}}{92.1 \bullet 60 \text{ minutes}} = 0.0175 \text{ scfm}$$

and

$$Qd = \frac{q \bullet k_{(mixing)} \bullet 10^6}{Cex \text{ (ppm)}}$$

$$Qd = \frac{0.0175 \bullet 1 \bullet 10^6}{10 \text{ (ppm)}} = 1{,}750 \text{ scfm}$$

Exercise 3. What is q, the volume flow rate of vapor formed, if 0.1 pounds of benzene are uniformly evaporated in a lab fume hood during an 8-hr period? What volume flow rate Qd is required for dilution to Cex = 1 ppm; let $k_{(mixing)} = 1$. (STP, MW = 78)

"Air changes per hour" is an antiquated term, but it is still used in some older standards and in some useful equations.

The terms N, and ACH stand for "air changes per hour," as in, "The insurance company requires six ACH in storage rooms containing flammable materials." Ideally, "air change" means replacing one volume of air in the space. In actuality, replacement depends on mixing efficiency.

The formula for air changes is

$$N = \frac{Q \bullet 60}{Vol} \qquad \left(= \frac{Q \bullet 3600}{Vol} \right)$$

where

N = number of air changes per hour, ac/hr

Q = the volume flow rate of air, cfm (cu m/sec)

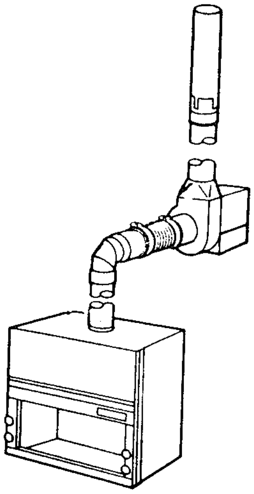
Vol = the space volume, cubic feet (cubic meters)

Example 3 Calculate N for the flow rate determined in Example 2. Assume a lab volume of 3,000 cu ft.

$$N = \frac{Q \bullet 60}{Vol}$$

$$N = \frac{1750 \bullet 60}{3000} = 35 \text{ ac/hr}$$

Exercise 4. Calculate N for the flow rate determined in Exercise 3. Assume a room volume of 4,000 cu ft.



Example 4. Assume that an existing lab fume hood exhausts air at a rate of Qd = 1,450 scfm. During a one-hour chemical operation, 0.4 lbs of pure formaldehyde are evaporated into the exhaust air. Sampling in the breathing zone of the employee suggests exposures averaging C_{bz} = 0.1 ppm during the operation. What is the approximate Protection Factor offered by the hood? What is the approximate rating according to the ASHRAE 110 standard?

$$q = \frac{387 \bullet \text{lbs evaporated}}{MW \bullet \text{minutes}}$$

$$q = \frac{387 \bullet 0.4 \text{ lbs evaporated}}{30 \bullet 60 \text{ minutes}} = 0.0860 \text{ scfm}$$

$$\text{Cex (ppm)} = \frac{q \bullet k_{(\text{mixing})} \bullet 10^6}{Qd}$$

$$\text{Cex (ppm)} = \frac{0.0860 \bullet 1 \bullet 10^6}{1450} = 59 \text{ ppm}$$

$$PF = \frac{\text{Concentration in exhaust air}}{\text{Concentration in the BZ}} = \frac{59}{0.1} = 590$$

The ASHRAE 110 gives the hood performance rating in the form of **xxAUyy,** where xx is the emission rate in liters/min, AU means "As Used," and yy is the exposure level in the breathing zone (actually using a manikin.)

$q = 0.0860 \text{ cfm} \bullet 28.3 \text{ lpm/cfm} = 2.4 \text{ lpm}$

therefore

ASHRAE rating = 2.4AU0.1

Exercise 5. Assume that an existing lab fume hood exhausts at a rate of Qd = 1,050 scfm. During a two-hour chemical operation, 0.6 lbs of pure benzene are evaporated into the exhaust air. Sampling in the breathing zone of the employee suggests exposures averaging C = 0.05 ppm during the operation. What is the approximate Protection Factor offered by the hood? What is the approximate rating according to the ASHRAE 110 standard?

Answers to Exercises

Exercise 1. A lab fume hood exhausts a total of 1,150 cubic feet per minute. Makeup air is provided by the HVAC system. The hood runs all day long in a lab of dimensions 12'x18'x9'.

What is the dilution volume flow rate? The number of air changes per hour in the lab?

The dilution ventilation volume flow rate must be at least equal to the exhaust rate. (Every cubic foot *must* be replaced.)

The minimum number of air changes per hour (ac/hr) is given by

$$N = \frac{Q \bullet 60}{\text{Vol}} = \frac{1150 \bullet 60}{12 \bullet 18 \bullet 9} = 35 \text{ ac/hr}$$

Exercise 2. Complaints and symptoms are suggestive of insufficient dilution air. However, until the following questions are answered, it will not be possible to specify dilution ventilation:

- Are most operations conducted in hoods?
- Are only reasonably non-toxic or non-hazardous chemicals being used on open benches?
- Are air contaminants primarily vapors or gases, or respirable sized aerosols?
- Do emissions occur uniformly in time?
- Are emission sources widely dispersed?
- Do emissions occur remote from lab workers breathing zones?
- Do moderate climatic conditions prevail?
- Is the outside air less contaminated than the inside air?

Positive responses to these questions *might* lead us to provide additional dilution ventilation. We could also decide independently on other control strategies (e.g., more or better lab fume hoods, improved work practices, training, better storage, and so forth.)

Exercise 3.

$$q = \frac{387 \bullet \text{lbs evaporated}}{\text{MW} \bullet \text{minutes}}$$

$$q = \frac{387 \bullet 0.1 \text{ lbs evaporated}}{78 \bullet 480 \text{ minutes}} = 0.0010 \text{ scfm}$$

and

$$Qd = \frac{q \bullet k_{(\text{mixing})} \bullet 10^6}{C_{\text{ex (ppm)}}}$$

$$Qd = \frac{0.0010 \bullet 1 \bullet 10^6}{1 \text{ (ppm)}} = 1{,}000 \text{ scfm}$$

Exercise 4.

$$N = \frac{Q \bullet 60}{\text{Vol}} =$$

$$N = \frac{1000 \bullet 60}{4000} = 15 \text{ ac/hr}$$

Exercise 5. Assume that an existing lab fume hood exhausts at a rate of Qd = 1,050 scfm. During a two-hour chemical operation, 0.6 lbs of pure benzene are evaporated into the exhaust air. Sampling in the breathing zone of the employee suggests exposures averaging C = 0.05 ppm during the operation. What is the approximate Protection Factor offered by the hood? What is the approximate rating according to the ASHRAE 110 standard?

$$q = \frac{387 \bullet \text{lbs evaporated}}{\text{MW} \bullet \text{minutes}}$$

$$q = \frac{387 \bullet 0.6 \text{ lbs evaporated}}{78 \bullet 120 \text{ minutes}} = 0.0248 \text{ scfm}$$

$$\text{Cex (ppm)} = \frac{q \bullet k_{(\text{mixing})} \bullet 10^6}{\text{Qd}}$$

$$\text{Cex (ppm)} = \frac{0.0248 \bullet 1 \bullet 10^6}{1050} = 24 \text{ ppm}$$

$$\text{PF} = \frac{\text{Concentration in exhaust air}}{\text{Concentration in the BZ}} = \frac{24}{0.05} = 480$$

The ASHRAE 110 gives the hood performance rating in the form of xxAUyy, where xx is the emission rate in liters/min, AU means "As Used," and yy is the exposure level in the breathing zone (actually using a manikin.)

$q = 0.0248 \text{ cfm} \bullet 28.3 \text{ lpm/cfm} = 0.70 \text{ lpm}$

therefore

ASHRAE rating = 0.7AU0.05

Chapter 17.
Design of Laboratory Fume Hood Duct Systems

The other ventilation approach is *dilution,* described in Chapter 16.

Local exhaust ventilation of lab-generated chemical contaminants helps to maintain safe and comfortable conditions for lab workers and students. Successful exhaust systems capture, contain, and remove contaminants from the lab area.

Use hoods whenever possible.

Lab fume hoods are the preferred ventilation method for most lab operations. The hood is attached to ductwork, fans, and discharge stacks.

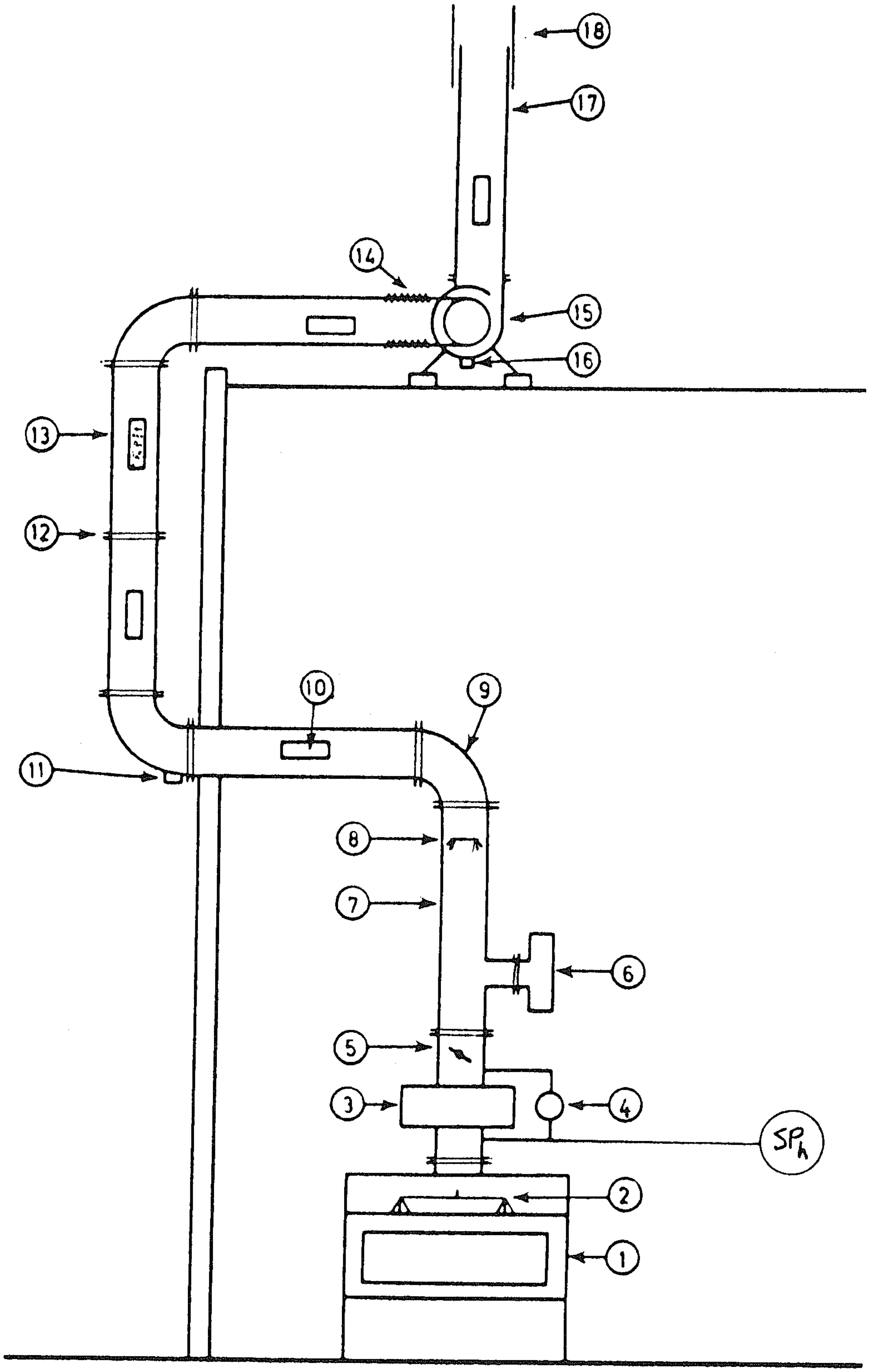
The contaminant may be scrubbed from the air stream or directly exhausted to the outside environment through stacks. (More information on air cleaning is presented at the end of this chapter.)

Need a review?

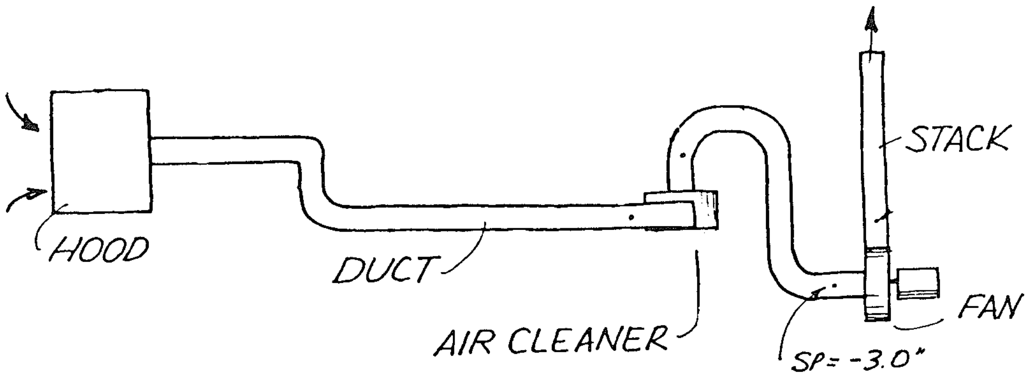
Before completing this chapter, please read Chapters 3, 4, and 5. In this chapter we will introduce the basic approaches to duct design for laboratory fume hoods. An indepth discussion of duct design is found in the *Industrial Ventilation Workbook.* (See Ref. No. 4.)

A lab fume hood exhaust system is shown below. Not all components are found in every hood exhaust system.

1. Lab fume hood
2. Fire extinguisher
3. Filter
4. Manometers
    - filters
    - hood SP
5. Damper
6. Air flow monitor
7. Ductwork
8. Water wash
9. Elbows, fittings
10. Cleanout
11. Drain connection
12. Air tight flanges on ductwork
13. Duct ID and warning labels
14. Flexible coupling
15. Air mover (fan)
16. Drain connection
17. Dispersion stack
18. Rain protection

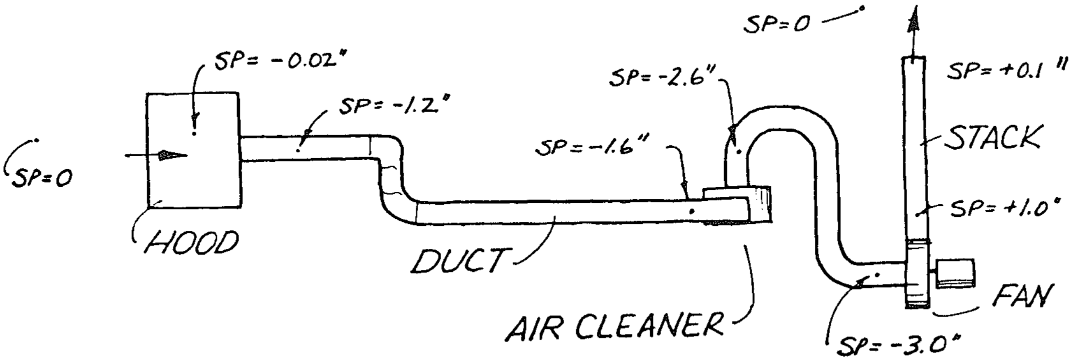


Air moves under the influence of pressure differences. A fan is commonly used to create the pressure difference. If a fan is capable of creating three inches of negative static pressure (e.g., 3” w.g., or “three inches water gauge”), as shown in the next figure, that pressure is available to move the air through the duct system.



“Potential energy” is converted to “kinetic energy” at the hood slot and duct entry.

Static Pressure (SP) is the potential energy of the ventilation system. It is converted to kinetic energy (VP) and other (less useful) forms of energy (heat, vibration, noise), the “losses” of the ventilation system. Typical static pressures in a system are shown below.



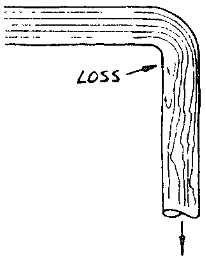
As the air moves through the duct, losses are created (i.e., static pressure is converted to heat, vibration, noise.) The loss is usually directly related to velocity pressure:

SP Loss = K • VP

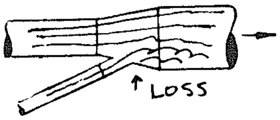
Where SP Loss = loss of static pressure, inches w.g.
K = loss factor, unitless
VP = velocity pressure in duct

See Ref. No. 4

Losses include hood entry, friction, elbow, branch entry, system effect, air cleaner, and others. The loss factors can be obtained from many reference sources. Those typically found in simple lab hood exhaust systems are included on Charts 7 and 8 in the Appendix.



The friction loss factor, K, and VP may be obtained from the second and fourth columns of the Nomograph, Chart No. 5. Note that the friction loss factor is given for 100 feet of duct. For friction, the above formula becomes



SP Loss = K/100 ft • VP • length of duct

Example 1. What is the friction loss in 20 feet of 10-inch galvanized duct, where the average velocity is V = 2000 fpm? (at STP)

Go to the Nomograph, Chart 5. Mark a point on D = 10" (first column), and V = 2000 fpm (fourth column). Draw and line and find K from the second column: K = 2.4/100 feet; VP = 0.25" w.g., from the fourth column.

SP Loss = K/100' • VP • 20'
= 2.4/100' • 0.25 • 20' = 0.12" w.g.

Exercise 1. What is the friction loss in 10 feet of 8-inch galvanized duct, where the average velocity is V = 2000 fpm?

Fume hood duct materials are chosen by their (2):

- weight and cost
- resistance to attack
- flammability and smoke ratings
- ease of installation
- ease of maintenance

Common fume hood duct materials include (2):

- Galvanized iron or steel—low cost, some corrosion protection
- Stainless steel—good corrosion protection except for HCl, high cost
- Asphalt-coated steel—resistant to acid, attacked by solvents, may not meet fire codes, mid-range costs
- Epoxy-coated steel—mid-range costs, select epoxy formulation for chemicals resistance
- Fiberglass—acid resistance, check fire codes, mid-range costs
- Plastics—ABS/PVC; selective chemical resistance, high costs, check fire codes
- Flex ducts—temporary installations, short life, avoid

Note that the friction loss factor K/100 from Chart 5 is for air moving through *galvanized ducts*. For non-galvanized duct materials, use the following corrections:

Duct Material	Correction Factor Cf (or R)
Smooth fiberglass, Stainless steel, ABS and PVC plastic	0.8 to 0.9
Spiral wound galvanized	1.1
Any flex duct	2.5 to 2.8

To use, multiply the friction loss factor (K/100 ft) by the Correction Factor, Cf.

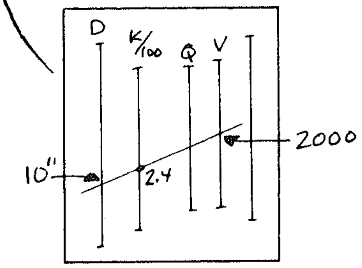
Example 2. What is the friction loss in 20 feet of 10-inch *stainless steel* duct, where the velocity is V = 2000 fpm?

Go to the Nomograph. Mark a point on D = 10" (first column), and V = 2000 fpm (fourth column). Draw and line and find K from the second column: K = 2.4; VP = 0.25" w.g., from the fourth column. The correction factor for stainless steel is Cf = 0.9.

SP Loss = K/100 • VP • 20 • Cf

= 2.4/100 • 0.25 • 20 • 0.9 = 0.11" w.g.

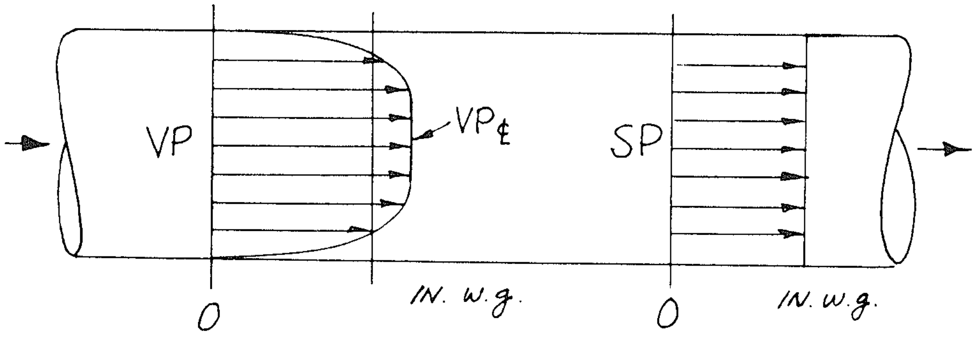
Exercise 2. What is the friction loss in 10 feet of 8-inch flexible duct, where the velocity is V = 2000 fpm?



Ductwork has the task of carrying air and entrained contaminants away from the lab fume hood for treatment/handling/exhaust. Ductwork must also provide a conduit for the negative static pressure to reach from the fan to the hood.

Air does not flow smoothly in lab fume hood exhaust ductwork. It is either totally turbulent, or approaching it. This turbulence assists in transporting particles through the ductwork. The turbulence actually scours particles off the duct surface as they settle. Different dust particles require different velocities. Most lab fume hood systems assume little dust loading, and velocities of 1500-2500 are typical.

As the air flows through the duct, it experiences friction as it rubs against itself and over the duct surface. (Rub your hands together—the heat you feel is created by the friction of rubbing.) The friction retards the velocity near the duct surface. As we proceed towards the center of the duct we would see increasing velocities, until we reached a plateau. See the next figure.



In long straight sections of duct:

- the velocity at the edge of duct is V = 0
- the velocity at the centerline is the maximum encountered (usually—there may be exceptions)
- the average velocity is somewhat less than the centerline velocity

One way of estimating the average velocity in a long straight section of duct is

$$\mathbf{V_{ave} = 0.9 \cdot V_{centerline}}$$

and if we substitute Bernoulli's equation for V,

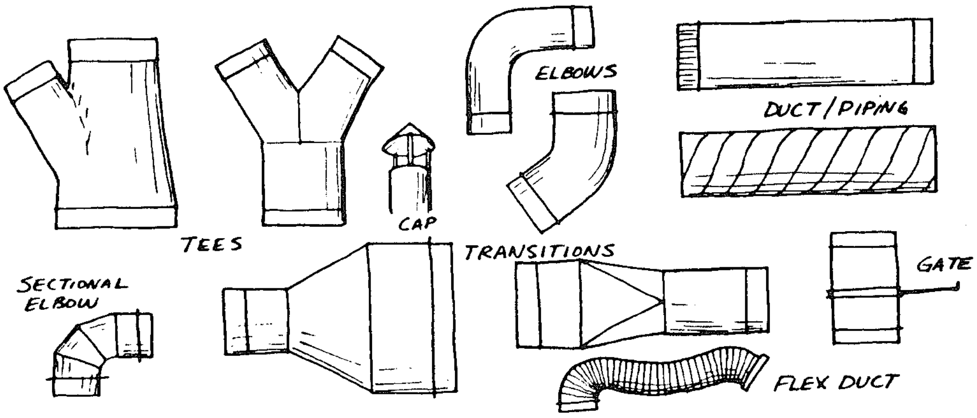
$$\mathbf{VP_{ave} = 0.81 \cdot VP_{centerline}}$$

A long straight section usually means at least five duct diameters downstream and three duct diameters upstream from any bend, obstruction, transition, etc.

Example 3. The centerline velocity in a long straight duct is V = 1,800 fpm. What is the predicted average duct velocity?

$$V_{ave} = 0.9 \cdot V_{centerline} = 0.9 \cdot 1800 = 1{,}600 \text{ fpm}$$

Exercise 3. The centerline velocity pressure in a long straight duct is VP = 0.33" w.g. What is the predicted average duct velocity pressure?



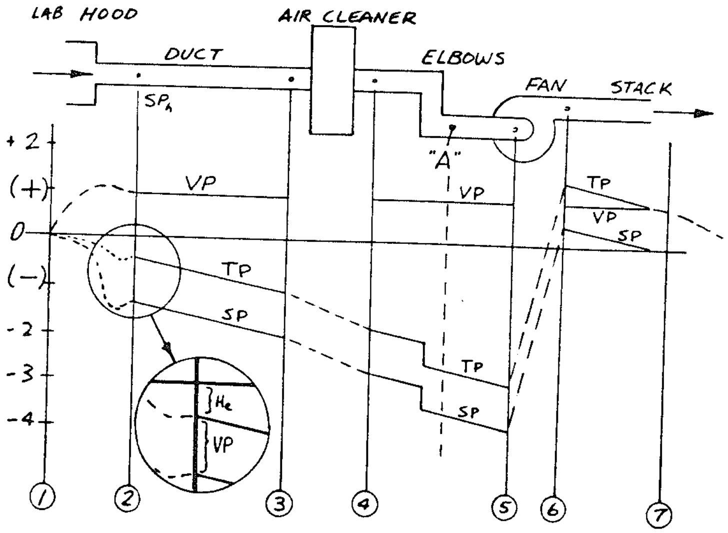
Fume hood exhaust ductwork usually consists of straight runs of duct, elbows, expansions and contractions, branch entries, dampers, stacks, rain protectors, and transition pieces to fans or air cleaners.

Every ventilation system is self balancing. This means it will take all the static pressure produced at the fan and distribute it throughout the system to assure balance. If we increase the static pressure at the fan, the system will readjust itself to restore balance. Similarly, if static pressure demand is reduced at one point in the system, the whole system will redistribute the additional static pressure at achieve a new balance.

We want to *predict and control* how the system balances itself. We want it to behave the way we desire it to behave. We want it to supply a specific static pressure at the hood—just enough to create the airflow we desire.

As shown on the next figure, static pressure at any point in the system is directly related to the requirements for air flow at that point. For example at the hood static pressure measurement point, No. 2, the static pressure is precisely the amount necessary to get air through the hood and flowing down the duct at actual duct velocity. The static pressure at the fan, point No. 5, is the amount required to move the air through the hood, down the duct, through elbows, etc., and to bring it at duct velocity to the fan entry.

If a hole were drilled at Point A and a pitot tube and manometer were used to measure pressures, VP would be 1 inch w.g., SP would be -3.9 inch w.g., and TP would be -2.9 inch w.g.



We will discuss fans in the next chapter.

Note also that static pressure requirements are additive as air moves toward the fan, from either end. The static pressure requirements in and out of the fan represent total air-handling system pressure requirements.

The Velocity Pressure Method of Duct Design

The velocity pressure method of design is a balanced design approach which attempts to equate losses to fractions of velocity pressure:

$$\textbf{SP Loss} = \textbf{K} \bullet \textbf{VP} \qquad \text{(at STP)}$$

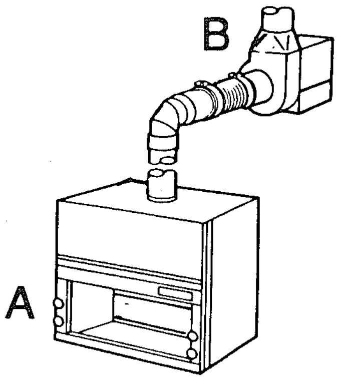
In any balancing method, the design process is an iterative, trial-and-error process. The designer tries different duct diameters, hood entry types, etc., until both branches are about equal in static pressure demand. Fortunately, a quick and easy calculation chart has been developed to minimize the trial-and-error process. And of course, with experience, design is often completed with very few iterations.

Its busy, but easy.

At first, the procedure will seem complicated, but actually it's quite simple.

Example 4. The next figure shows a lab fume hood to be installed in a lab. The hood is to exhaust Q = 1,000 scfm. Transport velocities need not exceed Vt = 2,000 fpm. Slot velocities will be Vs = 1,200 fpm at Q = 1000 scfm. We will use galvanized duct.

Given
Q = 1,000 scfm
V_{duct} = approx. 2,000 fpm
K_{hood} = 0.5
K_{elbow} = 0.4
Length A-B = 25'



These will be dictated by the physical layout of the system.

The data with the drawing indicates that the location of the fan must be 25 feet from the source. The sketch indicates a 90-degree elbow in the system. We will use galvanized duct and assume we are at standard conditions.

Standard methods call for labeling all entries, junctions, or other discontinuities with letter designations, i.e., labeling the FROM and TO locations. In the sketch, "A" is at the hood entry, and "B" is at the fan entry. "A" represents the FROM location; "B" represents the TO location.

Organize your data.

It is often useful to organize the raw data in tabular form.

Raw-data worksheet for system design

				------*Loss*	*Factors*	*K*--------	
Run	Q	Vt	L	Hood	Elbow	Entries	Other
A-B	1000	2000	25	0.50	0.40	---	---

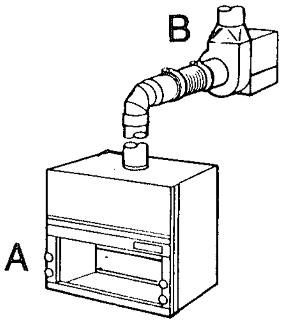
What remains is to choose a duct diameter, then determine the static pressures in the system up to the fan. A similar calculation can be performed for the ductwork downstream from the fan. We will only look at the upstream side in this chapter.

The next page shows the calculation sheet for the velocity pressure design procedure. Please turn to it and follow along as we describe each row.

Each design trial requires one column of the calculation sheet. Start at row one, column one.

Row 1. Duct ID. Enter the designated FROM and TO locations; in this case, branch "A —> B".

Row 2. Design Q. Enter the required volume flow rate; in this case, 1000 cfm. (Note that units are specified on the sheet—"cfm".)



Given

$Q = 1{,}000$ scfm

$V_{duct} =$ approx. 2,000 fpm

$K_{hood} = 0.5$

$K_{elbow} = 0.4$

Length A-B = 25'

Duct design by the velocity pressure method

ROW		ITEM	SOURCE	UNITS					
1	plans	DUCT ID	plans	FROM--TO	A-B				
2		Design Q		cfm	1000				
3		Transport Vel		fpm	2000				
4		Slotted hood?	(yes-row 5; no-row 12)		YES				
5	slots/plenums	Slot Velocity		fpm	1200				
6		Slot Area	(row 2/row 5)	sq ft	0.833				
7		Slot VP		in wg	0.09				
8		Entry Loss K Factor	(1.78)	--	1.78				
9		Acceleration Factor	(1.0)	--	1.00				
10		Plenum Loss Factor	(2.78)	--	2.78				
11		Plenum SP	(row 7 X row 10)	in wg	0.25				
12	ducts	Duct Diameter	Chart #5	inches	10				
13		Duct Area	Chart #5	sq ft	0.5454				
14		Duct Velocity	(row 2/row 13)	fpm	1833				
15		Duct VP		in wg	0.21				
16		Duct Length	plans	feet	25				
17		Friction Correction		--	1.0				
18		Friction K/100	Chart #5	--	2.4				
19	loss factor, K	Friction K	(rows 16x17x18/100)	--	0.60				
20		Duct ("Hood") Entry		--	0.50				
21		Acceleration	(1.0 at hoods)	--	1.00				
22		Elbows		--	0.40				
23		Branch Entry		--	0				
24		System Effect		--	0				
25		Other	( )	--	0				
26		Total K	(sum rows 19-25)	--	2.50				
27	static pressure	Duct SP	(row 26 X row 15)	in wg	0.53				
28		SP at FROM location	(Row 33)	in wg	0				
29		Jnctn VP change	(at FROM)	in wg	0				
30		Other SP loss	( )	in wg	0				
31		Total SP	(sum rows 11, 27-30)	in wg	0.78				
32	junction	Is this GOV SP?	plans	(yes/no)	X				
33		GOV SP	(at TO location)	in wg					
34		Actual Q	(row 2)(rows 33/31)$^{1/2}$	cfm					
35		SPh	(rows 11+(15x(20+21))	in wg	0.57				
36		Total Slot Length	plans	ft	X				
37		Slot width	12X(row 6/row 36)	inch	X				

D. Jeff Burton

Row 3. Transport Velocity. In this case insert Vt = 2000 fpm.

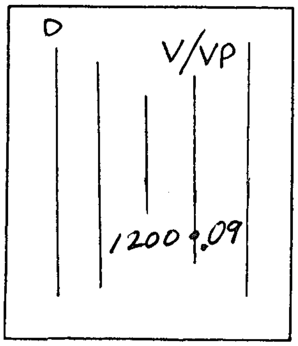
Row 4. Yes, this is a slotted hood. If you have data about the slots, use Rows 4 through 12.

[If you do not have data about the slots, answer "no," skip Rows 5-11, and use K = 2.0 in Row 20. This is a close approximation for most low velocity hoods.]

Let's assume we have the slot data from the hood manufacturer.

Row 5. The slot velocity is estimated to be Vs = 1200 fpm. [Data from hood manufacturer.]

Row 6. Divide Row 2 by Row 5.



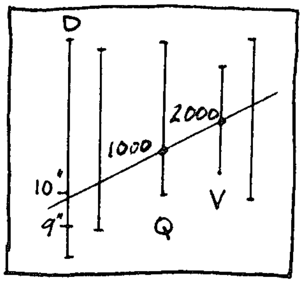
Row 7. You can find this on the fifth column of Chart 5 for a slot velocity of Vs = 1200 fpm.

Rows 8 and 9. These are almost always 2.78 and 1.00. (In the absence of other data, use these values.)

Row 10. Add Rows 8 and 9.

Row 11. Multiply Row 10 by Row 7. (This is K • VP.)

Row 12. Duct Diameter. The calculation sheet suggests using the Nomograph, Chart No. 5. Using Q and the transport velocity, draw a line to the diameter column. The figure shows the situation. The line connecting 1,000 cfm and 2,000 fpm is near a ten inch diameter duct.



Enter a 10" duct into Row 12.

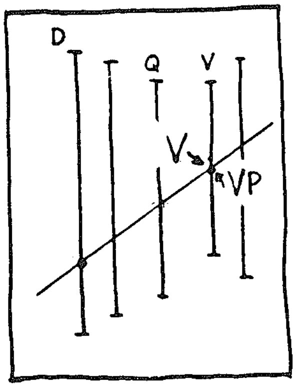
Row 13. Duct Area. This may be found on the Nomograph, or calculated.

Row 14. Duct Velocity. The instructions say divide Row 2 by Row 11, i.e., divide Q by A, giving velocity. In this case the velocity is 1833 fpm, only slightly less than our target velocity of 2000 fpm.

Exercise 4a. Using the second column on the calculation sheet, run a similar trial using a 9" duct. Fill in rows Row 1 through Row 14.

If a 9" duct is chosen, the velocity will be 2263 fpm, or slightly more than necessary. This is typical of the problems encountered during design.

Exercise 4b. Continue filling in the second column row by row as we finish column one.



Row 15. Duct VP. Calculate using Bernoulli's equation, or use Chart 5.

$$VP = (2263/4005)^2 = 0.32 \text{ inches w.g. (STP)}$$

Row 16. Duct length. This is a function of the physical layout of the system; in this case, the length is 25 feet.

Row 17. Duct friction correction factor, Cf. Select an appropriate correction factor for the duct material. In this case we'll use Cf = 1.0. (No correction for galvanized. See Chart No. 8 for other materials.)

Row 18. Duct Friction loss factor K per 100' of duct. Use the second column of the Nomograph, Chart No. 5.

Row 19. Actual duct friction loss Factor. Row 19 is obtained by multiplying Rows 16 • 17 • 18 and dividing by 100. This gives the friction loss factor for the actual length of duct in the system.

Row 20. Duct ("Hood") Entry Loss Factor. This is

K = 0.50 for straight takeoffs (no tapered entry to the duct from the hood plenum)
K = 0.25 for tapered takeoffs
K = 2.0 when Rows 5-11 are not used
K = value provided by hood manufacturer

Row 21. Acceleration Factor. This is always 1.0 when the "FROM" location is a hood. This factor accounts for the fact that air is accelerated from rest outside the hood to duct velocity in the duct, i.e., it takes "1 VP" of static pressure to accelerate air from zero velocity pressure outside to "one" velocity pressure in the duct:

Static Pressure need for acceleration = 1 • VP

Row 22. Elbow Loss Factor. (See Chart 7.) We have already been given the loss factor as K = 0.40.

Complete charts of loss factors are found in Reference No. 4

Row 23. Branch Entry Loss Factor K. This refers to a branch entry into a main duct. Since we have no branch entries, enter zero.

Row 24. System effect factor, K. We will assume no system effect loss. Enter zero. System effect factors are found in Reference No. 4.

Row 25. Special Fittings. This row is for special fittings or equipment, such as settling chambers, orifices, and so forth. In our example, there are no special fittings.

Row 26. Total of Duct Loss Factors. Row 26 is the summation of all the loss factors. Add rows 19-25.

Row 27. Duct SP loss. Row 27 is determined by multiplying Row 15 (actual VP) times Row 26, the sum of the loss factors of VP. Row 27 is the static pressure required to move 1,000 cfm into the hood and down the duct to point B at duct velocity.

Row 28. Static Pressure Loss, at "FROM." If Point A had begun at a junction for example, there would have been a Static Pressure demand up to Point A. Enter this value in Row 28. (Static pressures are additive from point to point, from junction to junction.) In the example, "FROM" was not a junction.

See Ref. No. 4 for calculation procedures

Row 29. Junction VP Change, at "FROM." If branch velocities entering the previous junction are less than the velocity leaving, static pressure is required. In the example problem, "FROM" was not a junction.

Row 30. Other SP Losses. If there are other static pressure losses to be accounted for, place them in Row 30. Examples include SP drops across air cleaners, contractions, and other equipment where the loss is specified in inches of water. In the example, there are no other losses.

Row 31. Total SP Losses. Row 31 = the sum of Row 11 + Rows 27-30. Row 31 represents the total static pressure required in the duct run A--->B.

Rows 32-34. Junction balancing calculations at "TO". These rows are used at a junction..

Row 35. Hood Static Pressure. SPh can be estimated by following the formula.

Rows 36 and 37. Procedures for estimating slot length and width are shown.

Finished. That's it—a duct run designed! The duct could be built with 10" galvanized duct, 25' long; the volume flow rate will be 1000 cfm, the duct velocity will be about 1833 fpm, and the inlet static pressure to the fan is about -0.78 inch w.g. The hood static pressure will be about SPh = -0.57" w.g.

Information on fan selection is provided in Chapter 18.

Exercise 4c. Compare the answers for a 9" duct with those of the 10" duct. Which would you be inclined to choose?

A similar calculation can be performed for a hood and branch duct that ends at a larger duct or plenum. Branch entry loss factors are shown on Chart 8.

A similar calculation can be made for the duct and stack on the down stream side of the fan.

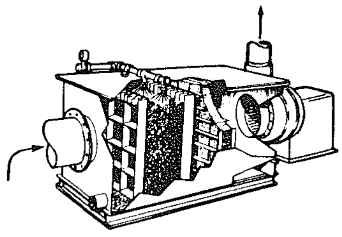
We also have a preprogrammed calculator which does all this automatically. Check out the last chapter of the workbook.

A more detailed explanation of the calculation procedure, including calculations for branched ducts is found in the *Industrial Ventilation Workbook.* See Reference No. 4.

Air Cleaners for Lab Fume Hood Exhausts

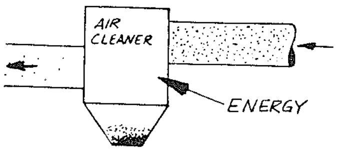
Since the 1970's, almost all air cleaning has been a function of the permit required by local, state, and federal codes. In most jurisdictions, you must obtain a permit any time a new stack is installed, or if older exhaust equipment is modified.

Always get that permit!



Air cleaning is a complicated subject. When you are ready to select an air cleaner, involve a consultant, or call on manufacturer's representatives. This section presents a brief overview of the subject. Additional information can be found in publications listed in the Bibliography.

Air cleaning = f (input energy)

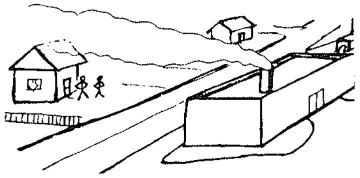


Effective separation of contaminants from an airstream is a function of the input energy—and energy input is directly related to costs.

For example, the larger the static pressure drop across a cyclone, the greater the collection efficiency and the higher the costs, all other things being equal.

This is not to say that one system is not more cost-effective than another. There are choices to make for cost effectiveness.

The following list provides several cautionary measures to take when selecting an air cleaner.

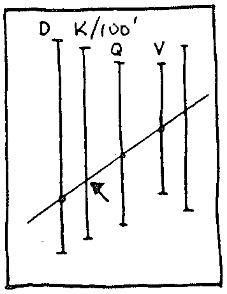


- Get a permit. It will tell you what you need.
- Ask for references from the supplier—who else has purchased the equipment? Call the other customer and find out how the equipment performed.
- Ask for a trial. Install the equipment with the understanding that you'll purchase it if it lives up to expected performance.
- Ask for guaranteed performance. Every reputable manufacturer is willing to specify and guarantee a minimum level of performance.

Exercise 5. You are involved in the design of a new operation to tear apart and evaluate failed circuit boards. The operation will be conducted in a lab hood. Some heavy metal dust and solvent vapors are expected to be exhausted, but the exact amount is not yet known. Your boss suggests you look into getting the proper permit from the local air pollution control authority.

How would you look into it?

Answers to Exercises



Exercise 1 . What is the friction loss in 10 feet of 8-inch duct, where the velocity is V = 2000 fpm? Go to the Nomograph. Mark a point on D = 8" (first column), and V = 2000 fpm (fourth column). Draw and line and find K from the second column: K = 3.2; VP = 0.25" w.g., from the fourth column.

SP Loss = K/100 • VP • 10 = 3.2/100 • 0.25 • 10 = 0.08" w.g.

Exercise 2. What is the friction loss in Exercise 1 if the duct is flex duct?

The correction factor is $Cf = 2.5$.

$\text{SP Loss} = K/100 \bullet VP \bullet 10 \bullet Cf = 3.2/100 \bullet 0.25 \bullet 10 \bullet 2.5 = 0.20$" w.g.

Exercise 3.

$VPave = 0.81 \bullet VPcenterline = 0.81 \bullet 0.33 = 0.27$" w.g.

Exercise 4.

You should have the following numbers

Row Number	
1-11	Same as Example 4
12	9"
13	0.4418 sq ft
14	2263 fpm
15	0.32 inch w.g. (or, 0.30" using Chart 5)
16-17	Same as Example 4
18	2.7
19	0.68
20-25	Same as Example 4
26	2.58"
27	0.83"
31	1.08"

Exercise 5. How would you look into it?

Call the local authorities and ask for information. You will have to gather lots of information—emission rates, future growth expected, times of emissions, and much more. It is unlikely, but you may be asked to provide filtration. In that event, you will need to ask the following questions:

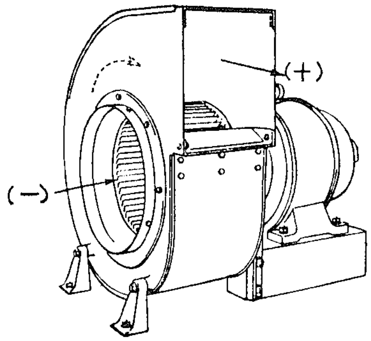
- What are all the objectives of the cleaning—Recirculation? Esthetics? Meeting air pollution codes only? Material recovery?
- What is the loading?
- What cleaning efficiency is possible?
- How much can you spend?
- What are the cleaning equipment alternatives? Initial costs? Operating costs?
- What other problems will be created? (Water pollution, solid waste disposal, new employee exposures, and so forth.)
- What is the required life expectancy?
- Local availability of service and maintenance?

Chapter 18.
Fans

The Air Moving and Control Association

Fans are used to move air in both exhaust and supply systems.

AMCA is the primary association for fans. AMCA has established definitions, rating criteria, and testing procedures which almost all fan manufacturers use. See the Appendix for the address. Always choose a fan with an *AMCA Certification.*



As the blade moves through the air, it physically moves a finite amount of air a few inches forward. New air immediately takes the place of air moved forward. The fan can be thought of as a bucket brigade, each blade representing one bucket (of air).

The fan also creates a positive static pressure on the forward side of the blade and a negative static pressure on the back side of the blade. These static pressures are transmitted downstream and upstream in the ductwork.

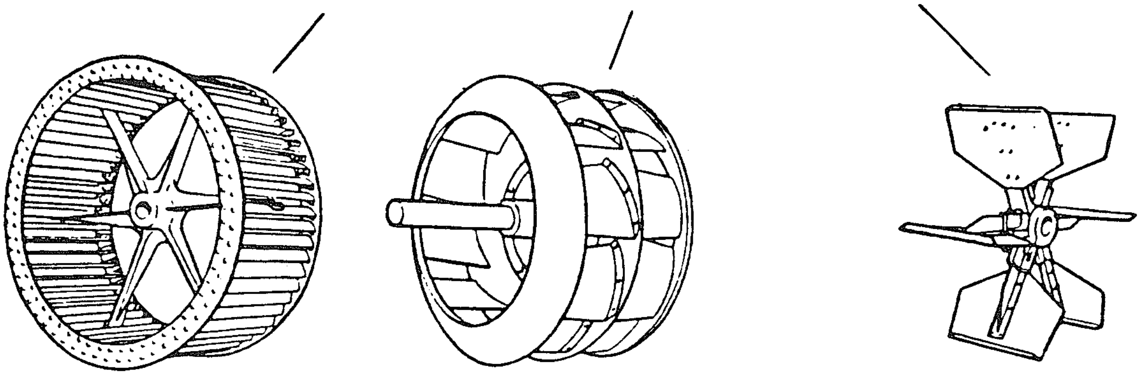
Get help.

The topic of fans is obviously complex. This *Workbook* presents introductory information for evaluation and specification of lab fume hood fans. For those interested in more detail, see the references in the Appendix.
Fan manufacturer representatives are good sources of information and can often provide the fan you need; but it's good to know what you want when you call, and to know whether you're getting the best fan available when something is suggested.

Types:
Axial and
Centrifugal

There are two basic families of fans: the axial and the centrifugal. Axial fans often have propeller-type blades. The wall fan and the free-standing room fan are typical forms of *axial fan.*

Centrifugal fans are normally found in lab fume exhaust systems. Within this group, there are three sub-groups: forward-inclined, backward-inclined, and radial wheels.



Sometimes called the "paddlewheel fan." Rarely used in lab fume hood systems.

The radial wheel is sometimes used in laboratory exhaust ventilation systems because of its rugged simplicity, low initial cost, ability to generate high static pressures, and its tendency to stay clean and resist the erosive forces of dust-laden air.

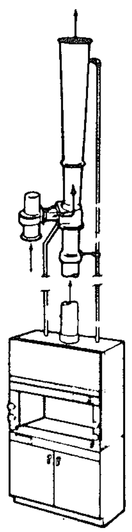
"BC" fan. Often used in lab fume hood systems.

The *backward inclined wheel* is often used when the air stream is relatively clean. Its primary benefit is that it has a flat horsepower curve, i.e., it is more difficult to overload the motor, and it is quiet and efficient. It is often used in HVAC systems.

"FC" fan. Sometimes used in lab fume hood systems.

The *forward curved wheel* is often used in small heating furnaces, like the one in your home. Its primary advantage is that it is quiet. Unfortunately, it is not very rugged and tends to clog or abrade in air contaminated with aerosols. It is often found serving small, individual lab fume hoods.

Induction "fans" keep moving mechanical parts out of the air stream.

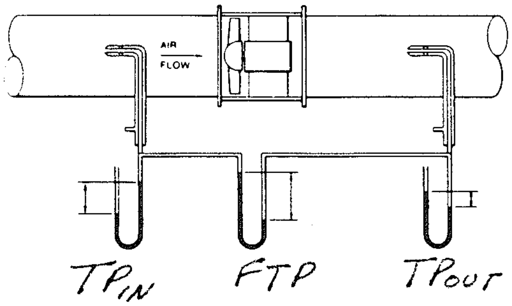


Induction air movers are sometimes used in perchloric acid fume systems. See references in the Appendix for details.

Fans are specified by pressure and flow rate. The pressure is normally measured across the fan—at the inlet and outlet of the fan in the ductwork.

The *fan total pressure*, FTP, represents all energy requirements for moving air through the ventilation system. FTP is calculated by adding the absolute values of the average total pressures found at the fan. If the sign convention is followed, then a formula for FTP is

$$\mathbf{FTP = TP_{(outlet)} - TP_{(inlet)}}$$



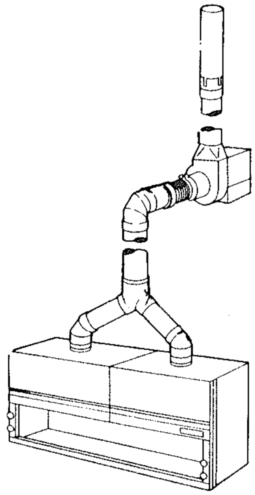
substituting TP = SP + VP gives

$$\mathbf{FTP = SP_{(out)} + VP_{(out)} - SP_{(in)} - VP_{(in)}}$$

If VP (out) equals VP (in), i.e., if the average inlet and outlet velocities are equal, then the VP terms in the above equation cancel, leaving

$$\mathbf{FTP = Sp_{(out)} - SP_{(in)}}$$

The FTP is often referred to as "the fan total static pressure drop."



Example 1. The inlet and outlet conditions of a fan are: Inlet TP = -0.75 inch w.g., Outlet TP = +0.10 inch w.g. What is the FTP?

$FTP = TP_{(out)} - TP_{(in)}$

FTP = 0.10" wg. - (-0.75") w.g. = 0.85" w.g.

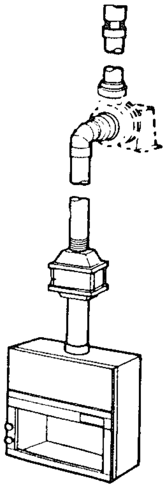
Exercise 1. The inlet and outlet conditions of a fan are:

Inlet SP = -2.50 in w.g., Outlet SP = +0.70 in w.g., Inlet and Outlet VP = 0.50 inch w.g. What is the FTP?

Don't forget to use the correct sign when using these formulas.

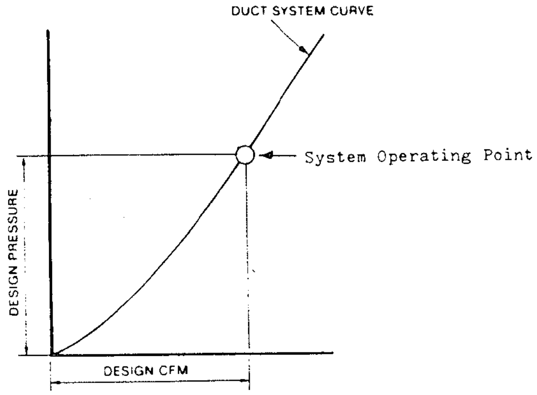
SOP

Understanding the *system operating point*, the *system curve*, and the *fan curve* will help you visualize how a fan is selected.



The adjacent figure presents a lab hood exhaust system. *"System"* in "system curve" refers to the ventilation system—hood, ductwork, and so forth.

During duct design we are interested in the desired Q and the static pressure necessary to deliver that desired Q. This point (Q, FTP) can be plotted on the graph and is called the *system operating point*. The SOP lies along a system curve, of course. See the next figure.

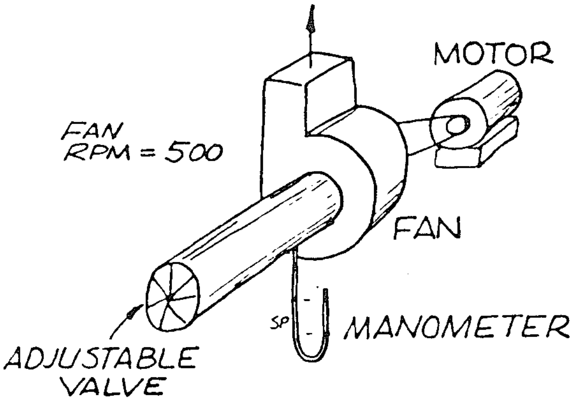


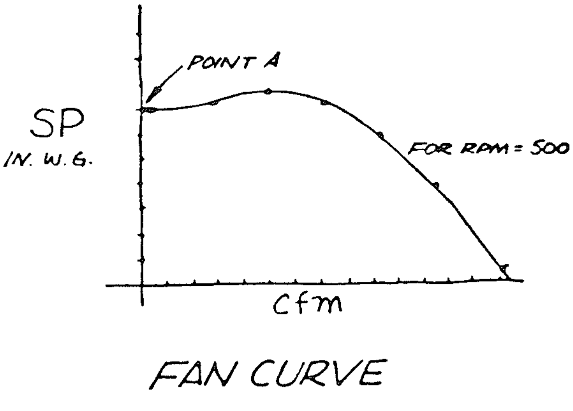
The resulting system curve looks like a quadratic equation because the change in static pressure is roughly equal to the square of the change in cfm.

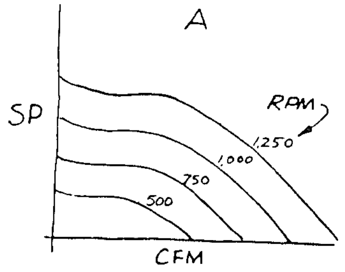
A *system curve* can actually be developed by turning the fan at different rpms and plotting the actual flow and the absolute values of the static pressures. At zero rpm, no flow occurs, and no static pressure is measured. As the fan is speeded up, more flow occurs, and more static pressure is measured. In practice, the system curve is mathematically plotted using the fan laws.

A *fan curve* is developed by using the method shown on the next figure. A short length of duct is installed on the inlet side of the fan and a butterfly valve is installed at the inlet to the duct. A static tap measures static pressure.

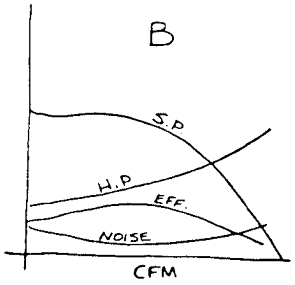
The fan is turned at a single, specified rpm. The valve is shut down completely, so that no air flows. See *Point A* on the curve. The butterfly valve is slowly opened and each time more air is allowed through the duct. Eventually, the valve is opened all the way, resulting in maximum flow ("free delivery") and essentially no static pressure losses.





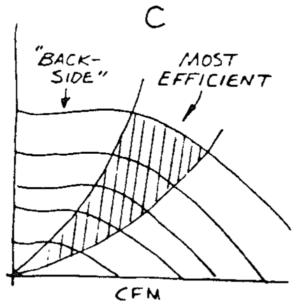


Additional curves can be generated by turning the fan at different rpms. Thus a family of rpm curves can be generated for any fan.



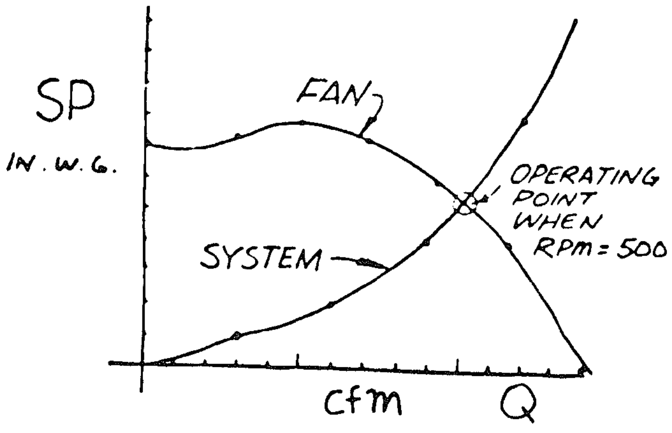
Other parameters can also be measured and plotted, e.g., horsepower consumed, efficiency, noise levels, and so forth.

Usually, we are interested only in the more efficient operating range of the curve. Therefore, fan manufacturers usually print only the area shaded on the next figure.



Normally, fans should not be operated on the curve left of the peak SP. This is operating on "the backside of the fan curve." Problems of air instability, vibration, noise, inefficient operation, and low flow rate are encountered on the backside."

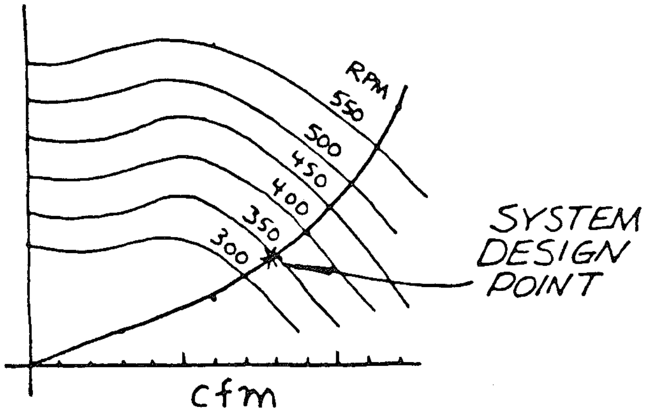
Take the system curve and the fan curve and overlay them.



The point where the curves cross is where the system would operate if the fan were installed in the system.

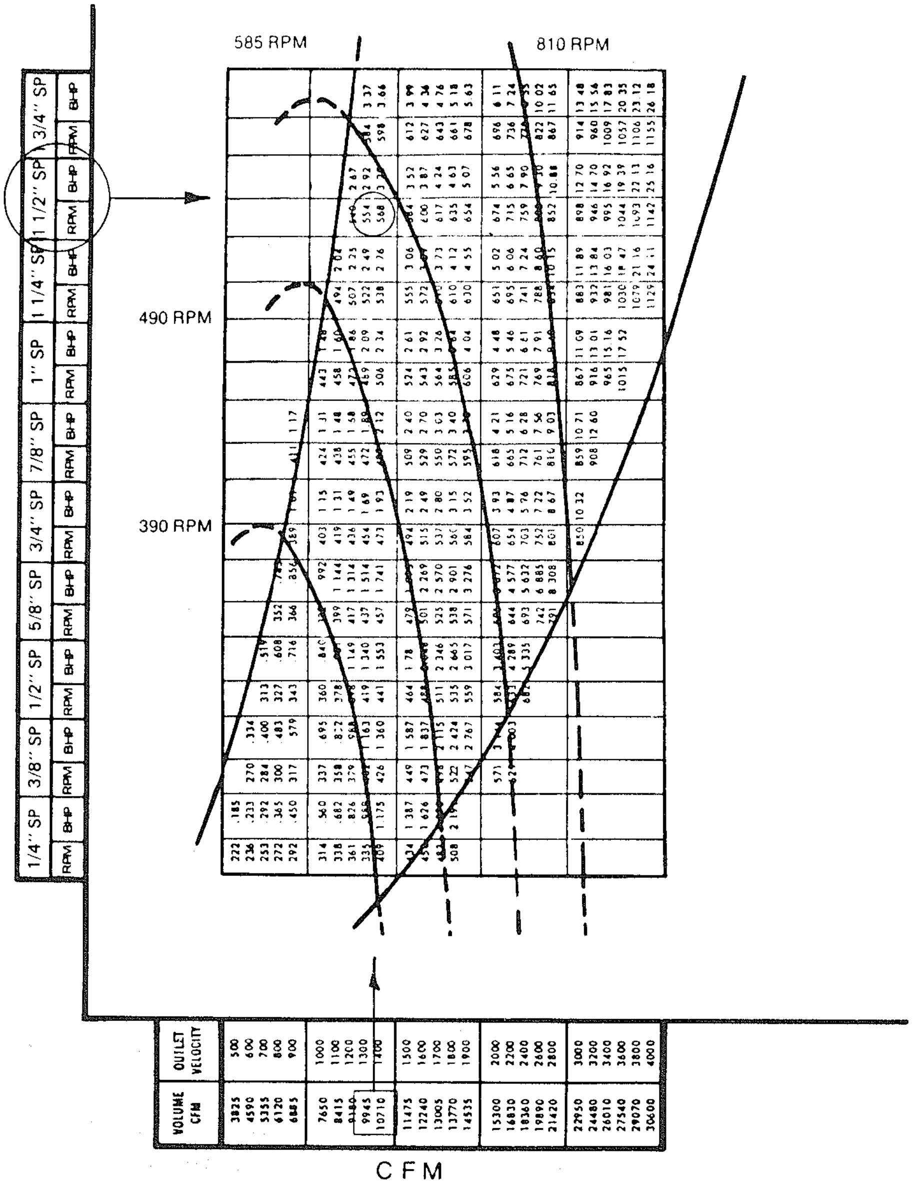
Of course, during system design, we always specify a desired static pressure and flow rate, i.e., we choose, in advance, the "system operating point" on the system curve that we need. Let an asterisks (*) be our design criteria on the next figure.

A fan must be chosen that has an RPM line that falls across the system operating point that we specify.



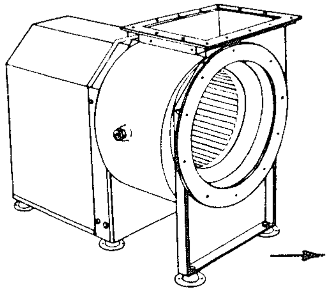
Essentially, that's how to specify a fan. There's more to it, of course, so we'll talk about specification procedures later in this chapter. And, it's important to consult with several fan manufacturer representatives while considering fan selection, if you have that responsibility.

The following figure shows a ***fan table*** with the equivalent fan curves superimposed over it. Tables are easier to read and less intimidating to some people. Usually, you will want to choose a fan in the middle range of the table.

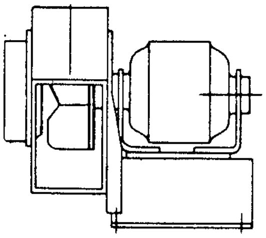


REORIENTATION OF A TYPICAL FAN PERFORMANCE TABLE SHOWING SIMILARITY WITH A FAMILY OF CONSTANT SPEED PERFORMANCE CURVES

The next figures show commercial fan tables. Note that the tables have cfm and pressure listed as parameters, along with rpm, efficiency, bhp, class, and other information.



Motor H.P.	Phase	Wheel RPM	CFM@ ¼″ S.P.	CFM@ ⅜″ S.P.	CFM@ ½″ S.P.	CFM@ ⅝″ S.P.	CFM@ ¾″ S.P.	CFM@ 1″ S.P.	CFM@ 1¼″ S.P.	CFM@ 1½″ S.P.	CFM@ 1¾″ S.P.
¼	1	996-1385	525-720	450-715	350-725	335-670	380-605	440	...	...	...
⅓	1	1304-1562	755-850	710-805	650-855	585-820	510-775	400-660	515	...	...
½	1	1495-1894	905-1140	865-1105	820-1065	775-1030	720-995	590-975	515-890	550-785	575-680
¾	1	1017-1245	...	1690	1510	1350-1510	1120-1515	648-1265	648-1120	777	...
1	1	1085-1308	1950	1840	1680-1810	1510-1800	1345-1660	907-1560	648-1405	777-1036	...
1½	3	1181-1500	2130	2040	1955-2120	1800-2000	1660-2050	1265-1890	907-1860	777-1540	907-1460



Model No.	Motor H.P.	Blower RPM	PERFORMANCE—CFM AT 1750 RPM								
			½″ S.P.	⅝″ S.P.	¾″ S.P.	1″ S.P.	1¼″ S.P.	1½″ S.P.	1¾″ S.P.	2″ S.P.	2¼″ S.P.
KE- 8	⅙	1750	365	275	150	....	....	....	....	....	....
KE- 9	¼	1750	635	565	480	200	....	....	....	....	....
KE-11	½	1750	1225	1165	1100	945	730	430	....	....	....
KE-12	1	1750	2060	1975	1890	1700	1485	1185	750	350	....
KE-14	2	1750	3025	2925	2820	2595	2350	2045	1620	1010	640

Example 2 Choose an appropriate fan for a system operating point of Q = 1,000 scfm and FTP = 1.5” w.g..

From the first table, at rpm = 1300, Q = 1036, SP = 1.5" w.g., and rated motor hp = 1.0

This is a pulley driven fan and rpm can be adjusted. The “SP” is FTP, presumably. (We have to ask to be sure.)

From the second table, Model KE-11, rpm = 1750 (a direct drive fan), Q = 1185, and rated motor hp = 1.0

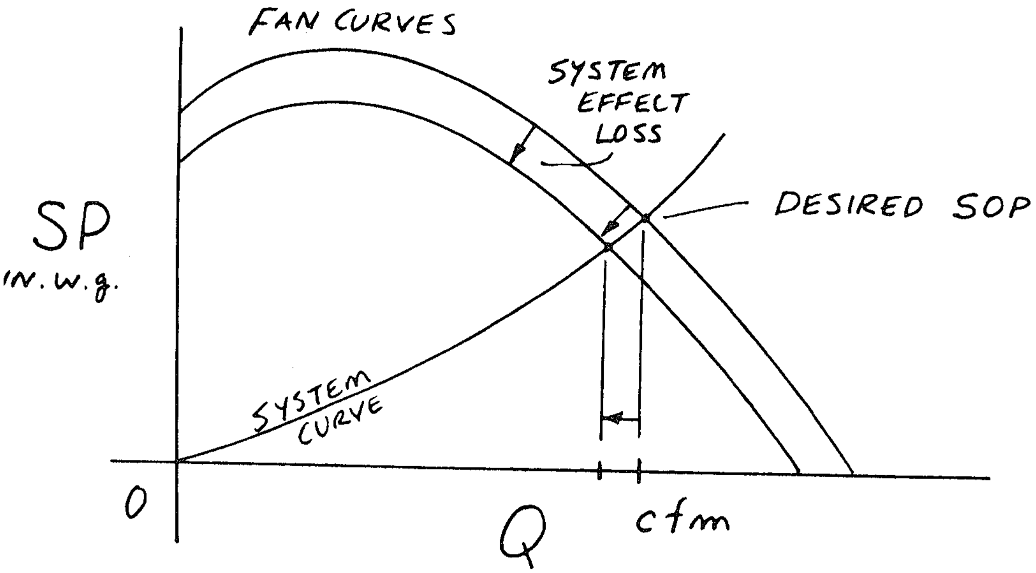
This is as close as we can come with direct drive.

Exercise 2. Find a fan and an appropriate rpm for a system exhausting 1,400 cfm at a FTP of 2.0 inch w.g.

The mysterious and dreaded SE loss—thousands of hood ventilation systems are deficient because of this little-known loss.

Fans tested under AMCA rules are tested under ideal conditions. If these same fans are used under less than ideal conditions, they will not perform to their rated capacity. This loss is called the *system effect loss* and occurs when air does not enter and leave the fan wheel in the smooth, uniform, balanced manner found during testing.

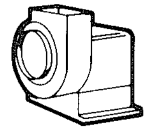
The loss effect is shown in the next figure. The actual fan curve during operation simulates a fan curve of lower rpm when it experiences a system effect loss. Note that it is not possible to measure the system effect loss because the loss occurs inside the fan. (Talk about frustration.) And the loss can be significant, particularly in lab hood exhaust systems—it is not uncommon to see a 20-30 per cent loss of flow.

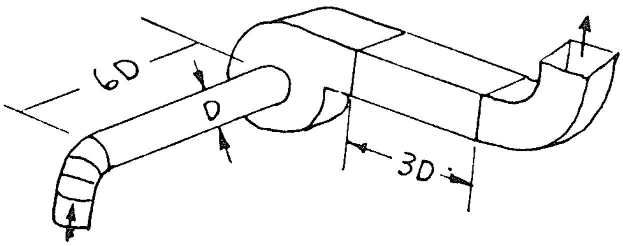


AMCA has estimated the system effect loss for various conditions. It is beyond the scope of this book to explain the calculations in detail. (See the *Industrial Ventilation Workbook,* Ref No. 4.)

The "Six and Three Rule"

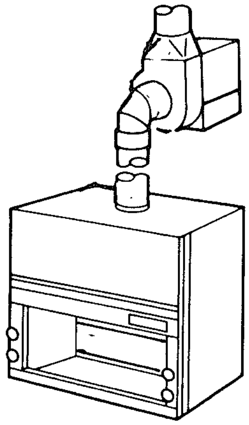
However, to avoid the system effect loss in round ductwork, a simple rule can be remembered: "six in and three out." This means six duct diameters of straight duct into a fan, and three duct diameters of straight duct out of a fan before any elbows. (The system effect loss is caused by placing elbows close to the fan which in turn imbalances air loading at the fan.) At the fan outlet, it is usually possible to avoid elbows by exhausting vertically.





Example 3. How many lengths of straight duct should be provided into and out of a fan which has 10" round ductwork?

Using the six-and-three rule, we should provide five feet of straight duct into the fan, and 2.5 feet of straight duct out of the fan.



Exercise 3. A fan serving a lab fume hood is to be located on the roof. A 12" duct comes out of a hole on the roof and through a 90-degree, 3-piece elbow before entering the fan. How many feet of straight duct should be provided at the fan inlet?

Motors and drives

Once you have selected a fan, you'll need a motor to drive it. But what size?

To size a motor, you need to know the definitions of air horsepower (ahp), brake horsepower (bhp), shaft horsepower (shp), and rated horsepower (rhp).

ahp

Air horsepower refers to the minimum amount of power to move a volume of air against the fan total pressure. It represents the power to get the air through the system. At STP, the formula is given by

$$\mathbf{ahp} = \frac{\mathbf{FTP} \circ \mathbf{Q}}{\mathbf{6356}}$$

where

FTP is Fan Total Pressure, inches w.g.
Q is volume flow rate, scfm

As we noted earlier, nothing gets accomplished without a little loss. And fans are no exception. Actually, the fan is an inefficient device. When the fan moves the specified cfm against the specified FTP, it wastes much of the input power (as much as 60% for small fans found in hood exhaust systems.)

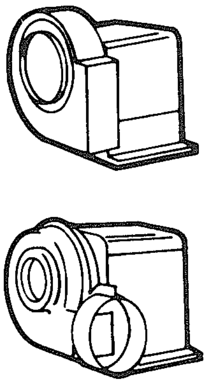
bhp

Brake horsepower refers to the actual horsepower required to operate the fan so that it fulfills its job of moving the specified cfm against the specified FTP. It takes into account the fan efficiency. The brake horsepower is air horsepower divided by a mechanical efficiency factor, *eff,* or

$$\mathbf{bhp} = \frac{\mathbf{ahp}}{\mathbf{eff}} = \frac{\mathbf{FTP} \circ \mathbf{Q}}{\mathbf{6356} \circ ME}$$

The efficiency factor, *ME,* is determined experimentally by the fan manufacturer.

shp *Shaft horsepower* is bhp plus any power required for drive losses, bearing losses, and pulley losses between the fan and the shaft of the motor. Normally, shp for a pulley driven fan can be estimated by



shp = bhp • Kdl

where Kdl is about:

= 1.25 for pulley drives (small motors on lab fume hood exhaust systems)
= 1.05 for direct drive

rhp *Rated horsepower* (sometime called motor hp) is normally the nameplate horsepower. A "2 hp" motor means that the motor is designed to draw up to two horsepower's worth of current from the electrical lines. It doesn't mean that the motor will always be supplying two horsepower any more than a 100-hp car always delivers 100 horses.

Example 4 What is the required horsepower for the system, and what rated horsepower motor would you choose?

System parameters:

FTP = 2.0 inch w.g.	ME = 0.50
Q = 1,300 scfm	Kdl = 1.25

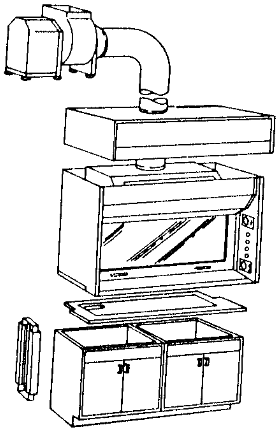
$$\text{bhp} = \frac{\text{ahp}}{\text{eff}} = \frac{\text{FTP} \bullet \text{Q}}{6356 \bullet \text{ME}}$$

(Not rounded for significant figures)

$$= \frac{2.0 \bullet 1{,}300}{6356 \bullet 0.50} = 0.82 \text{ hp}$$

$$\text{shp} = \text{bhp} \bullet \text{Kdl} = 0.82 \bullet 1.25 = 1.02$$

rhp (rated horsepower) must be more than 1.02 hp, say "1.5 rhp." Lab hood exhaust systems often call for the rhp to be 33% more than shp.



Exercise 4 Estimate the ahp, bhp, shp, and the rated horsepower motor you would choose for the following lab fume hood exhaust system.

FTP = 3.0 inch w.g.
Q = 1,800 scfm
ME = 0.55
Kdl = 1.25

Get help.

Selection of fans and motors is complex, particularly if you also have variable speed drives, inlet and outlet dampers, and so forth. Bring in some help.

Fan laws

Some of the most useful of the ventilation formulas are those known as "the fan laws." They may seem difficult, but the way we use them, they're quite simple.

Using the fan laws, we can estimate changes in a ventilation system when one operating parameter is changed. For example, suppose the rpm of a lab fume hood fan is changed. What is the new fan total pressure? The new horsepower required? The new flow rate, Q? The new lab fume hood face velocity? The fan laws help to predict these before the change is made.

The rpm fan laws are summarized below. The numbers 1 and 2 refer to conditions "one" and "two", or conditions before and after a change.

$$Q_2 / Q_1 = (RPM_2 / RPM_1)$$

$$SP_2 / SP_1 = (RPM_2 / RPM_1)^2$$

$$HP_2 / HP_1 = (RPM_2 / RPM_1)^3$$

Example 5. What is the new flow rate, hood static pressure, and horsepower expected when rpm is increased to **n** = 1,125 rpm?

Initial Conditions	Conditions after Increase
RPM = 1000	RPM = 1125
Q = 1,000 scfm	Q = ?
SPh = 0.85 inch w.g.	SPh = ?
shp = 0.50	shp = ?

$$\frac{RPM_2}{RPM_1} = \frac{1125}{1000} = 1.125$$

Therefore $Q_2 = Q_1 \bullet 1.125 = 1{,}125$ scfm

$SP_2 = SP_1 \bullet (1.125)^2 = 1.08$" w.g.

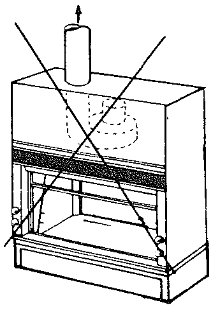
$shp_2 = shp_1 \bullet (1.125)^3 = 0.71$ hp

Exercise 5. Estimate new operating conditions for the lab fume hood system if fan belts slip, slowing fan rpm by 10%. (Fan belts will have a shorter life.)

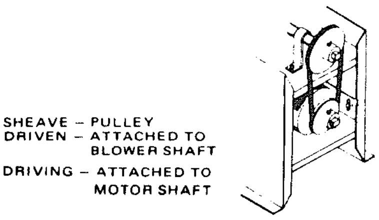
Initial Conditions	Conditions after decrease
RPM = 1500	RPM = 1350
Q = 1500 scfm	Q = ?
FTP = 2.1 inch w.g.	FTP = ?
shp = 1.25	shp = ?

Specification criteria

When specifying a fan, the designer should be prepared to provide the following information to the fan supplier.



Location	• Fans serving exhaust hoods should be mounted outside the building (not at the hood)
Wheel type and material	• Axial or centrifugal, radial, forward-curved, backward curved; materials of construction.
Volume flow rates	• The volume flow rate in scfm or acfm should be specified.
Dust loading	• In extreme cases, dust loading may affect the density of the air-dust mixture. However, in most laboratory applications, air-dust mixtures will not affect air densities. A more important factor is the effect of an aerosol. If an aerosol is present in the air stream, material may build up on fan blades, or blades may be worn away.
Solvents and gases	• The fan supplier will be looking for flammable and explosive conditions. If such is possible, the supplier may recommend spark-free wheels, isolated bearings, and so forth. Additionally, vapor may condense in the fan housing, causing trouble; although this a rare occurrence. A more common problem in lab fume hood systems is *acid mist*, which may corrode fan blades, housings, and fittings.
Inlet and outlet conditions	• Poor inlet and outlet conditions will adversely affect the performance and efficiency of a fan. The loss is called the "System Effect Loss" and may be very severe.
Couplings, transitions, and dampers	• The supplier will want to know the type of couplings and transitions to ductwork. Inlet and outlet velocities should be discussed. Dampers may be required on some systems. Inlet dampers enable the user to safely and economically reduce air flows.
Motor	• The supplier will want to check your figures. The last thing you want is to get an undersized motor that either burns up or refuses to do the work you require.
Drive	• Several types of drives may be chosen. The common types are belt-driven and direct-drive. The


SHEAVE – PULLEY
DRIVEN – ATTACHED TO BLOWER SHAFT
DRIVING – ATTACHED TO MOTOR SHAFT

direct-drive type is more efficient, may be cheaper, and eliminates slippage. The belt-drive offers flexibility, easy rpm adjustment, and limited motor protection. Recently, variable speed motors and drives have become popular. Always specify belt guards.

Fan discharge

- Will the outlet point upward? To the horizontal? This is an important consideration to help avoid system effect losses.

Access

- Always specify access to the housing. Fan blades wear out, sometimes rapidly. Maintenance activities should include periodic fan inspection.

Bearing type

- Will bearings be sleeve bearings or ball bearings? Are bearings to be sealed?

Flex couplings

- The ductwork installer usually installs these, but if the fan supplier asks, request them. The flexible coupling inhibits the travel of vibration and noise down the duct.

Noise ratings

- Fan noise is related to tip speed, rpm, type of blade, distance, and so forth. As a general rule, all other things being equal, noise is lowest at
  - maximum operating efficiency
  - when using fans with less blades
  - when operating at lower rpm
  - when using forward-curved blades
- Noise is usually specified according to *NC and RC ratings*. Check the bibliography for more details.

Vibration isolation

- Generally, ask for vibration isolation.

Weather protection

- Special weather housings are available. Drains are useful.

Stack

- A stack may dictate the type of outlet, mount, foundation and support, and outlet pressure.

Safety first!

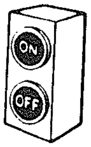
Exercise 6. A specifications checklist is found in the Appendix. (See Checklist No. 16.) Please turn to it now. Try to evaluate a fan in your building. Use existing plans, drawings, specifications, maintenance records. Take the responsible person with you to the site.

Fan selection criteria when using fan curves and tables

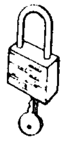
Fans are normally selected for *actual* cfm and *standard* static pressures. For more information, see Chapter 20 of this *Workbook* (or, the *Industrial Ventilation Workbook,* Chapter 9.)

Safety first!

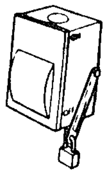
Working with fans can be dangerous. People have lost fingers and hands, and some have been killed when pulled into the rotating blades. Always lock out the electrical system before inspecting or working on a fan. Watch for pinch points on pulley wheels. Be sure access doors are closed before reactivating the fan. Always have someone in attendance who knows how the fan operates.



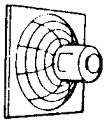
REMOTE SWITCH



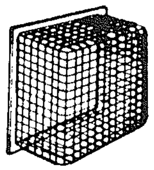
LOCK CARRIED BY MAINTENANCE PERSONNEL



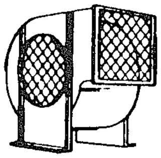
DISCONNECT SWITCH



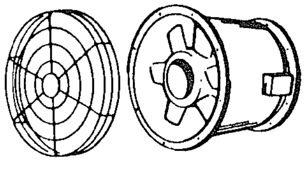
INDUSTRIAL TYPE GUARD FOR PROPELLER FAN



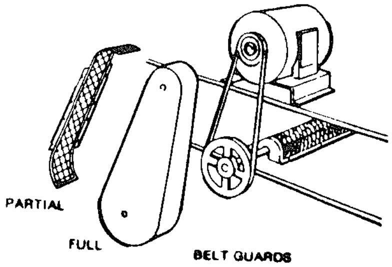
MAXIMUM SAFETY GUARD FOR PROPELLER FAN



INLET AND OUTLET GUARDS ON CENTRIFUGAL FAN WITH NON-DUCTED INSTALLATION



GUARD FOR AXIAL FAN WITH NON-DUCTED INLET OR OUTLET



BELT GUARDS

Case Study

Fan Clubs

Your Notes:

Al, the lab supervisor in the Highway Maintenance Section of the County Complex, had called June with a request. June recalled the incident with a sigh.

"I was enjoying a little rest from County problems. I was assigned to work with the County Attorney on a new lab safety standard." She paused to reach for some papers. "That OSHA 1450 regulation...we were updating our Chemical Hygiene Plan. It had to be ready by January 31st. We let things ride out to the last minute, as usual." She sighed again.

"Anyway, Al was complaining about the lab hoods in his soils lab. Those folks do a lot of analysis on soils, concrete, asphalt, paints, and other materials used on roads. I'm not sure what all...." She stopped and searched through some papers, finding a report she generated after the investigation. "We've had endless problems with the lab hoods down there."

Al complained that almost all the air flow in the basement hoods was gone. He told June that face velocities had dropped to less than 20 fpm. The three hoods involved were all attached to a single fan on the roof, three stories above.

June continued. "I pulled out the most recent testing records. Our last face velocity tests showed averages running around 70 feet per minute—not very good in a busy lab. Smoke containment had been okay, though—no signs of hood leakage. Our report—now six months old—had recommended an upgrading of the hoods. We wanted a consultant called in to give them some recommendations, but it never happened. Budget problems, as I recall," June said.

Exercise 7. Given the information provided by June, what might be happening? What could cause an almost total reduction of airflow at the hoods in the basement?

June continued her story. “A *small* reduction might be related to fan speed—slipping belts, for example. So that didn't seem likely. A large cutoff of almost all flow might be a fan turning backwards, a damper closed, or a hole in the downstream ductwork. It could have been a lot of things.” June shook her head as she thought about the difficulty of inspecting the entire duct system. Added after the building had been built, the ductwork snaked up through the three stories of the building through narrow utility chases, along closed crawl spaces, and behind newly constructed walls. “Seeing the whole system was going to be difficult,” June said. “I wish these things could be easier.”

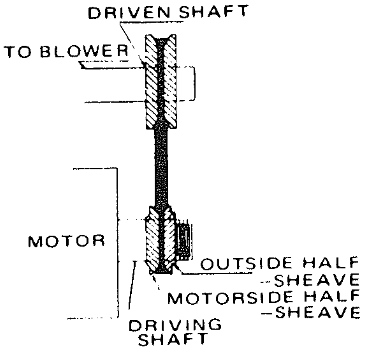
Ted's head appeared in the doorway. “If things were easy, they wouldn't need us,” he said, dropping a report in June's **IN** basket. “Gotta go,” he said, slipping out the door with a wave of his hand.

“He's headed downtown to check out another lab ventilation system. But back to the Al's problem. I went down to the Highway Lab and we tromped around the basement. Work had stopped. Without hoods no one could do anything. Al looked pretty upset.”

Air was flowing into the hoods, but at a very low velocity. June used smoke tubes to detect the movement. It was about 20 fpm, just as Al said.

“We went to the roof. I shouldn't laugh—Al was so embarrassed. Somehow, during the night, the breaker switch to the fan had been tripped. The fan simply wasn't running.” June chuckled. “We both got fooled because of the low air flow. We just assumed the fan was turning. Actually, the warm air in the building was creating a buoyant, gravity-induced flow. Just like in your chimney at home.”

While she was there, June had checked out a few other items. “The fan was being driven by a 2-belt pulley system. One of the belts was broken, and the other was



cracked and ready to break. I suggested to Al that he get those belts replaced. I reminded him to get them tightened after a couple of weeks. New belts tend to stretch and slip if you don't tighten them after a short period of use. I also noticed that the belt guards were gone. Al agreed to get someone on it right away."

June sat back, her hands behind her head, chuckling. "Some problems are easy. Some are really stupid, too."

Answers to exercises

Exercise 1.

FTP = Sp (out) - SP (in)

FTP = 0.70" wg. - (-2.50") w.g. = 3.20" w.g.

Exercise 2. From the first table, at rpm = 1308, Q = 1405, SP = 1.25" w.g., and rated motor hp = 1.0

This is a pulley driven fan and rpm can be adjusted.

From the second table, Model KE-11, rpm = 1750 (a direct drive fan), Q = 1485, and rated motor hp = 1.0

Exercise 3. The "six and three" rule says we should have 6x12" = 72" of straight duct into the fan.

Exercise 4

$$\text{bhp} = \frac{\text{ahp}}{\text{ME}} = \frac{\text{FTP} \bullet \text{Q}}{6356 \bullet \mathit{ME}}$$

$$= \frac{3.0 \bullet 1{,}800}{6356 \bullet \mathit{0.55}} = 1.54 \text{ hp}$$

$$\text{shp} = \text{bhp} \bullet \text{Kdl} = 1.54 \bullet 1.25 = 1.93$$

rhp (rated horsepower) must be more than 1.93 hp.

Exercise 5

The ratio of RPMs is 0.90.
Therefore $Q_2 = Q_1 \bullet 0.90 = 1{,}350$ scfm

$$FTP_2 = FTP_1 \bullet (0.90)^2 = 1.70\text{" w.g.}$$

$$shp_2 = shp_1 \bullet (0.90)^3 = 0.91 \text{ hp}$$

You can see why fan speed VAV systems are popular.

Exercise 6. This exercise is intended to acquaint you with the checklist.

Exercise 7. Given the information provided by June, what might be happening?

A small reduction might be related to fan speed--slipping belts, for example. A wholesale cutoff of almost all flow might be a fan turning backwards, a damper closed, or a hole in the downstream ductwork.

Chapter 19. Troubleshooting and O&M

Troubleshooting

Troubleshooting takes time and work

Occasionally, something will go wrong with laboratory ventilation systems. You may be asked to help troubleshoot the problem. Your investigation will be more effective if it is organized.

Checklist No. 1 *Lab Problem Investigation Checklist* provides an organized approach to conducting an investigation. Many times, the problem may be identified in the first few steps. If so, simply terminate the investigation at that point.

Often times, someone in the lab will have knowledge which will help you find the cause of the trouble. An excellent place to begin is with the lab supervisor.

Checklist No 4 *Interview with Lab Supervisor* provides a starting point for your discussions.

Checklist No's 5-7 may be used to organize additional preliminary data gathering.

Exercise 1. Turn now and review Checklist Nos 1, 4, 5, 6, and 7.

Comments and notes.

Form No. 2 *Laboratory walk-through survey worksheet* provides a way of conducting the initial assessment of a lab. It will guide you to further testing and/or monitoring. (See Chapter 10.)

Exercise 2. Turn to Form 2. Using the form, evaluate a lab. If you do not have access to a lab, review the form and use it evaluate a lab you have worked in (e.g., as a student.)

Comments and notes.

Form No. 5 *Lab Ventilation Deficiency Report Form* provides another excellent tool for evaluating a lab ventilation system.

Exercise 3. Turn to Form 5. Using the form, evaluate a lab. If you do not have access to a lab, review the form and use it evaluate a lab you have seen in the past (e.g., as a student.)

The following paragraphs list some common maladies or complaints and their potential causes. The first list refers to HVAC and makeup air systems, the second, to lab fume hood exhaust systems.

HVAC and supply air complaints:

Do you know of any such complaints in your facilities?

Make notes here:

Complaint: Temperature too warm. Temperature too cold. Air too dry. Air too humid.

Potential Causes: HVAC or supply air controls may be malfunctioning. Controls need adjustment.

Complaint: Air stuffy, stagnant. There is no air movement.

Potential Causes: Insufficient air supply to space; fan off, ducts disconnected, or dampers malfunctioning.

Complaint: There is no air movement when it gets cool in the lab or lab office spaces.

Potential Causes: VAV system cuts air to space because cooling is not called for.

Complaint: Too many drafts, too much air movement in lab.

Potential Causes: Air supply to lab too high; distribution within lab improper.

Complaint: Air smells has musty, “dirty sock ” smell.

Potential Causes: Mold in supply system.

Complaint: Air smells like diesel exhaust.

Potential Causes: Air supply intake near loading dock.

Complaint: The pressure in the lab is greater than the pressure in the hallway; pressure between rooms is excessive.

Potential Causes: Balance between supply and exhaust not appropriate; supply air not adequate.

Fume hood-related deficiencies or complaints:

Do you know of any such complaints in your facilities? Make notes here:

Deficiency or complaint: Excessive odors and fugitive emissions from the hood, but air flow volumes and hood face velocities are at design levels.

Possible Causes: If the equipment is okay, then the problem might be with management-related deficiencies. Example include:

- Improper use of the hood
- Improper hood
- Work practices are incorrect
- The ventilation system interferes with work or worker productivity so workers avoid use of hood
- Employees are not cooperating
- Employee training is not adequate
- No established policy for fugitive emission reduction

Deficiency or complaint: Reduced face velocities, excessive fugitive emissions.

Possible Causes: The cause is probably a reduced flow rate. Reduced flow rate occurs in the following situations:

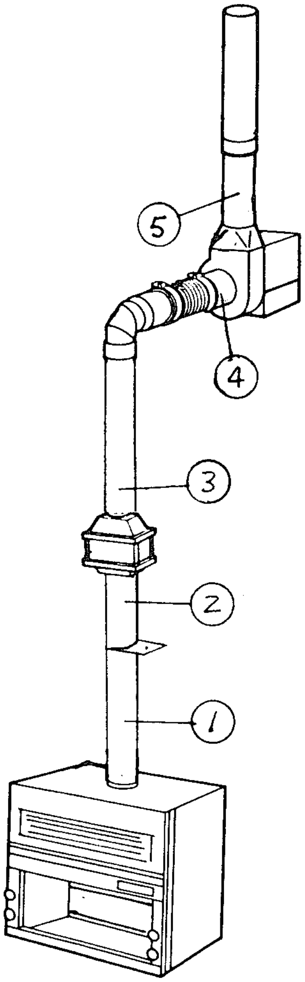
- Plugged or dented ducts
- Slipping fan belts
- Open access doors
- Holes in ducts, elbows
- Damper closed to branch, or opened dampers to other branches
- Fan turning in reverse direction (This condition can occur when wires are reversed, causing the motor and fan to turn backwards. Centrifugal fans turning

backwards can deliver up to 50% of rated capacity.)

- Worn out fan blades
- Additional branches or hoods added to system without a change at the fan.
- Clogged air cleaner

Deficiency or complaint: Worker complaints, misuse of hood, nonuse of hood, alteration of ventilation system by employees.

Possible Causes: The hood interferes with work; the hood provides poor control of contaminants.



Exercise 4. Examine the following table of static pressures. Each line represents a separate trouble spot in a laboratory hood system. Determine the probable cause and its location in the system.

Assume Bypass-type lab fume hood.

Hints: Estimate Fan Total Pressure (Point 4 + Point 5).
Look at Hood Static Pressure (Point 1). It is related to volume flow rate.

Static Pressures at five points, inches w.g.
(Note: all pressures negative, except Point No. 5)

Point No.	1	2	3	4	5
Desired Pressures ---------->	0.75	0.80	1.80	2.00	0.10
1st problem	0.35	1.80	2.30	2.40	0.05
2nd problem	0.10	0.11	0.20	1.50	0.25
3rd problem	0.60	0.64	1.55	1.70	0.08
4th problem	0.40	0.43	2.20	2.30	0.05
5th problem	0.50	0.53	1.40	1.50	0.90
6th problem	0.73	0.81	1.85	2.05	0.10
7th problem	0.75	0.80	2.00	2.00	0.10
8th problem	0.65	0.68	1.50	2.35	0.07

Operation and Maintenance Programs

What is your responsibility? Should you be involved?

You might want to take an active interest in the operation and maintenance of lab ventilation systems. It can save you a lot of time later, and will help safeguard the health and well being of lab users.

A good O&M program will help to:

- Maintain the effectiveness of the system over time.
- Continue to protect employees and comply with local and national standards.
- Help retain the value of the system.

It is amazing to see systems costing thousands of dollars left to deteriorate, sometimes in only a few weeks or months.

Elements of an O&M program:

Plan

(1) Commit the program to paper. No program survives unless it is a written program.

Record keeping

(2) Establish a safe place to file away drawings, hood and fan specifications, fan curves, operating instructions, and other papers generated during design, construction, and testing.

Inspection

(3) Establish a program of periodic inspection. It might go something like this:

- Daily: visual inspection of lab hoods, ductwork, access and cleanout doors, damper positions, hood static pressure, pressure drop across air cleaner, and verbal contact with users. ("How's the lab hood performing today? ")
- Weekly: Air cleaner, fan housing, pulley belts, stack.
- Monthly: Air cleaner components.
- Quarterly: System flow rates, fan rpm.

(3, continued) The type and frequency of inspection depends on the operation and other factors. You must meet the OSHA requirements for lab operation, as a starting point. See Chapter 12.

Checklists help those of us with poor memories.

The Appendix provides several inspection checklists, recording forms, and aids to testing. These should be used only by those qualified by training and experience to inspect a ventilation system—*you* for example if you've been trained to do so.

The checklists in the Appendix are provided as *samples* of checklists you might develop for your operations.

A checklist is a handy reminder but it doesn't tell you HOW to check.

PM

(4) Establish a preventive maintenance program. Certain elements of any system should be checked and replaced if defective, or replaced on a regular schedule (e.g., filters.)

Training

(5) Provide worker training. Show them how to work safely and how to best utilize the laboratory ventilation system.

Records

(6) Keep written records of all activities associated with the ventilation system.

Exercise 5. Consider one of the ventilation systems in your laboratory. (If you don't have access to a lab, imagine one you've seen during schooling, or elsewhere.) Outline a simple O&M program which includes:

- Written documents to be included in the data base
- Initial measurements to be made, recorded, and stored
- Inspections: Type, frequency, and responsibility
- Preventive maintenance provisions
- Worker training provisions

Answers to Exercises

Exercise 1. Review Checklist Nos 1, 4, 5, 6, and 7.

Checklists are useful as memory joggers. They do not teach you much.

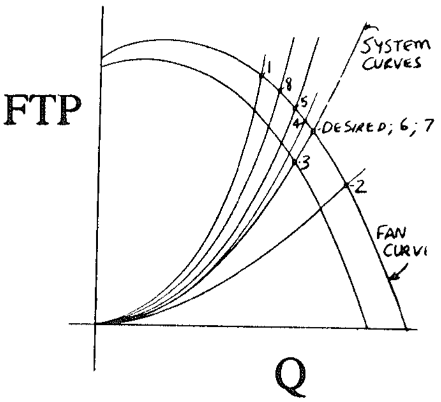
Exercise 2. Review Form 2.

You will want to make copies of these forms if you wish to use them later. However, it is best to modify all checklists and forms to suit your needs.

Exercise 3. Review Form 5.

This is a very useful form. It can be filled in and submitted to the lab supervisor as a report.

Exercise 4. Examine the following table of static pressures. Each line represents a separate trouble spot in a laboratory hood system. Determine the probable cause and its location in the system.



1st Problem -- Damper between points 1 and 2 partially closed.

2nd Problem -- Hole in flex duct at fan.

3rd Problem -- Fan belt slippage (about 10 percent).

4th Problem -- Clogged air cleaner.

5th Problem -- Blockage in stack. (Bird's nest? Snow?)

6th Problem -- No problem. Differences in readings represent normal variations in reading manometers and other natural variables.

7th Problem. -- Misread manometer, or recorded data incorrectly at Point No. 3. This is a common problem.

8th Problem -- Blockage in duct between Point No. 3 and Point No. 4. Could be settled material, dent in duct, flex duct pulled into duct.

Chapter 20

Non-standard air conditions

For ACGIH, STP is 70° F, 29.92" Hg., and dry air.

Throughout the *Workbook,* we have assumed standard conditions (STP), i.e, 29.92 inches Hg, 68° Fahrenheit, and 50% relative humidity. At these conditions, the density of air is

w = 0.075 lbs/cu ft

This is usually acceptable for installations near sea level.

Air density means little on a day-to-day basis. Most people are equally at ease at sea level or in the mountains at 5,000 feet. Temperature and humidity do alter our sense of comfort, however. At low humidities, for example, dry air makes people more sensitive to irritating and sensitizing chemicals.

The major effects of non-standard air densities or changing humidities on lab ventilation systems are described in the following paragraphs.

Density Correction Factor

All other conditions equal, air density varies linearly with the change in absolute temperature. Similarly, air density varies linearly with the change in air pressure. For example, if the air pressure increases by 10%, the density will increase by 10%. Or, if the absolute temperature increases by 10%, the density will decrease by 10%. These two relationships are combined into an equation called the Ideal Gas Law.

Air's weight-to-volume ratio (lbs/cu.ft.), or *weight density,* varies with temperature and pressure. For example when air is heated, it expands and its density decreases; when air moves to a higher altitude, and the barometric pressure drops, air expands and its density decreases.

Using the Ideal Gas Law, we can calculate a "density correction factor," **d.** This factor can be used to correct measured air velocities to actual velocities, actual volume flow rates to standard volume flow rates, and so forth. At standard conditions d = 1.0. At higher temperatures and altitudes, d is less than one; at lower temperatures and altitudes below sea level, d increases above one.

$$\mathbf{w\ (actual) = w\ (standard) \bullet d}$$

The Density Correction Factor can be calculated or looked up on a chart. The formula is

$$\mathbf{d = \frac{(530) \bullet (B.P.)}{(F + 460) \bullet (29.92)}}$$

where

d = density correction factor, unitless
B.P. = barometric pressure, inches Hg
F = temperature, degrees Fahrenheit

A list of density correction factors is presented in Chart 6. (Please find the chart in the Appendix.) It is accepted practice to extrapolate linearly between whole numbers.

Example 1. Estimate the density correction factor,d, for air at 100° F and 29.92 mm Hg.

From Chart 6, d = 0.95

Exercise 1. What is the density correction factor for air flowing in a lab fume hood duct system at 100° F and 5,000 feet altitude?

Example 2. What is the weight density (w) of air at T = 100°F and 5,000 ft altitude?

From Exercise 1, d = 0.79

w (actual) = w (standard) • d
= 0.075 • 0.79
= 0.059 lbs/cu ft

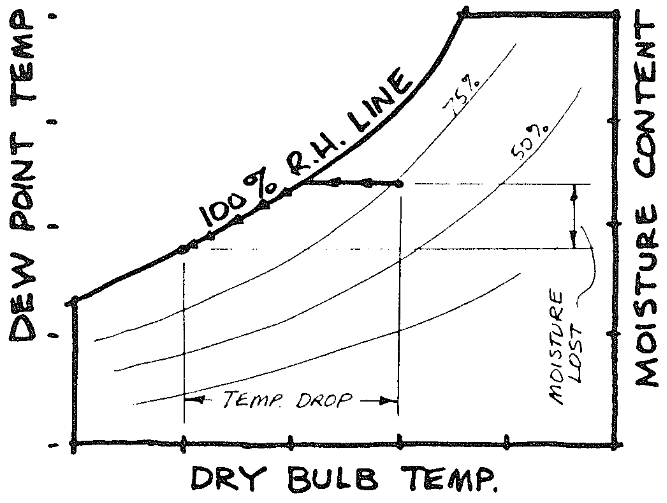
Exercise 2. What is the weight density (w) of air at T = 100° F and 3,000 ft altitude?

Issues related to Relative Humidity

Condensation

Humidity has very little influence on air flow in lab fume hoods. One possible problem related to humidity is the condensation of water in the ductwork. This can occur when hot moist air (e.g., from a boiling-water experiment in the lab fume hood, for example) cools in the ductwork as it goes outside the building. [Another problem can occur immediately downstream of a cooling coil or dehumidifier.]

As the air is cooled in the downstream duct, its ability to hold water decreases. If the air cools to below the dew point temperature (the temperature of 100% relative humidity), water condenses out of the air stream. See the simplified psychrometric chart below.



We rarely need to worry about humidity when *measuring* air flows and pressures.

However, at high temperatures (air temperatures greater than 100° F) you may need to take humidity into account. The discussion is beyond the scope of this book, however. Check Reference No. 2.

Issues related to flow rate

We usually assume incompressible flow in a single ventilation system.

Density changes do not effect the formula Q = VA for a single lab hood exhaust system where the pressure and temperature remain essentially constant. However, we do need to know whether the flow occurs at standard or non-standard conditions, and whether the velocity V is estimated from a measured value of VP. Flow rates in HVAC systems may be effected by air density, but the discussion is beyond the scope of this *Workbook.*

Measuring air velocity

Check product literature before purchase, if possible.

When measuring the velocity of air using a velometer, adjust the measured value to compensate for the actual air density. Each velometer or anemometer has a different correction procedure. See the monitoring equipment's technical or operating literature.

Measuring air velocity pressure

Modified Bernoulli equation

The formula for estimating velocity from VP when the air is at non-standard conditions is given by

$$V = 4005(VP/d)^{1/2}$$

Example 3. Suppose you measure the average velocity pressure in a duct at VP = 1.0 in w.g. The density correction factor d = 0.70.
What is the actual velocity, V?

Using the equation shown above, the velocity is

$$V = 4005(VP/d)^{1/2} = 4005(1.0/0.7)^{1/2}$$

$$= \underline{4{,}800 \text{ fpm}}$$

Exercise 3. Air flows in a round duct at T = 100° F, altitude = 5000 ft. The average velocity pressure is VP = 0.82 inches w.g. What is the actual velocity in the duct?

Note: The nomograph on Chart No. 5 is designed for air at standard conditions.

Correcting emission rate and dilution ventilation equations for non-standard conditions

When solvents evaporate under non-standard conditions the resultant vapor volume must be corrected. The formula is

$$\mathbf{q = \frac{387 \bullet Lbs}{MW \bullet min \bullet d} \quad in\ acfm}$$

Example 4. A boiling solvent evaporates at a high rate into a lab hood. Find the vapor generation rate in acfm if six lbs are uniformly evaporated over a two-hour period. MW = 48, d = 0.80. What is the concentration in the exhaust air if Q_{exh} = 1,200 acfm? (Assume perfect mixing.)

$$q = \frac{387 \bullet \text{Lbs}}{\text{MW} \bullet \text{min} \bullet \mathbf{d}} \qquad \text{acfm}$$

$$= \frac{387 \bullet 6}{48 \bullet 120 \bullet \mathbf{0.80}} = \underline{0.5039\ \text{acfm}}$$

The concentration in exhaust air is given by

$$C = \frac{q}{Q_{exh}} \bullet 1{,}000{,}000 \qquad \text{ppm}$$

$$= \frac{0.5039\ \text{acfm}}{1{,}200\ \text{acfm}} \bullet 1{,}000{,}000$$

$$= \underline{420\ \text{ppm}}$$

Exercise 4. Benzene evaporates into a lab fume hood. Find the vapor generation rate in acfm if 0.3 lbs are uniformly evaporated over a six hour period. MW = 78, d = 0.95.

What is the concentration in the exhaust air if Q_{exh} = 1,600 acfm?

Duct design and fan selection

Corrections for duct design

To correct duct design calculations follow these steps:

1. Pick volume flow rates, velocities, and design the system as if at standard conditions.
2. Pick the fan at Q = acfm and FTP = sFSP (i.e., standard fan total pressure.)
3. Reduce the motor shaft horsepower by the density correction factor:

   $$\text{shp (actual)} = \text{shp (design at STP)} \bullet d$$

4. After the system is built, if you measure static pressures in the system, they will be reduced by the density correction factor. For example

   $$\text{SPh (actual)} = \text{SPh (STP)} \bullet d$$

Example 5. A lab fume hood exhaust system is to be built and installed in Denver, Colorado (d = 0.80). The total volume flow rate for three hoods should be

Q = 4,500 acfm. The duct system is designed as if at standard conditions and FTP = 2.20 inches w.g., shp = 3.12 hp.

- When choosing the fan, what values of Q and FTP should be used?

According to Step No. 2 (above), choose the fan from the fan curves at Q = 4,500 cfm, FTP = 2.20" w.g.

- What shp should be used in the selection of the motor?

shp (actual) = shp (design at STP) • d
shp (actual) = 3.12 • 0.8 = 2.5 hp

- If after installation we measure the FTP, what pressure would we expect to measure?

FTP (actual) = FTP (STP) • d
= 2.20 • 0.80 = 1.76 " w.g.

Exercise 5. A lab fume hood exhaust system is to be built and installed in Salt Lake City, Utah (d = 0.85). The volume flow rate for the hood is to be **Q** = 1,200 acfm. The duct system is designed as if at standard conditions and **SPh** = -0.65 inches w.g., **shp** = 1.75 hp.

- When choosing the fan, what value of **Q** should be used?

- What **shp** should be used in the selection of the motor?

- If after installation you measure the **SPh**, what pressure would you expect to measure?

Answers to Exercises

Exercise 1. What is the density correction factor for air flowing in a lab fume hood duct system at 100° F and 5,000 feet altitude?

From Chart 6, d = 0.79

Exercise 2. From the chart, d = 0.85

$$
\begin{aligned}
w\ (\text{actual}) &= w\ (\text{standard}) \bullet d \\
&= 0.075 \bullet 0.85 \\
&= 0.064\ \text{lbs/cu ft}
\end{aligned}
$$

Exercise 3. Air flows in a round duct at T = 100° F, altitude = 5000 ft. The average velocity pressure is VP = 0.82 inches w.g. What is the actual velocity in the duct?

From the chart, **d** = 0.79

$$V = 4005(VP/d)^{1/2} = 4005(0.82/0.79)^{1/2}$$

$$= 4{,}100\ \text{fpm}$$

Exercise 4. Benzene evaporates into a lab fume hood. Find the vapor generation rate in acfm if 0.3 lbs are uniformly evaporated over a six hour period. MW = 78, d = 0.95.

What is the concentration in the exhaust air if Q_{exh} = 1,600 acfm?

$$q = \frac{387 \bullet \text{Lbs}}{MW \bullet \text{min} \bullet \mathbf{d}} \text{ in acfm}$$

$$= \frac{387 \bullet 0.3}{78 \bullet 360 \bullet .95} = 0.0044\ \text{acfm}$$

The concentration is given by

$$C = \frac{q}{Q_{exh}} \bullet 1{,}000{,}000 \quad \text{in ppm}$$

$$= \frac{0.0044 \text{ acfm}}{1{,}600} \bullet 1{,}000{,}000$$

$$= 2.7 \text{ ppm}$$

Exercise 5. A lab fume hood exhaust system is to be built and installed in Salt Lake City, Utah (d = 0.85). The volume flow rate for the hood is to be **Q** = 1,200 acfm. The duct system is designed as if at standard conditions and **SPh** = 0.65 inches w.g., **shp** = 1.75 hp.

- When choosing the fan, what value of **Q** should be used?

According to step no. 2, choose the fan at Q = 3,600.

- What shp should be used in the selection of the motor?

Sometimes we leave the shp at the STP value because it allows the motor to run a bit cooler. At higher altitudes, the air cannot cool the motor as efficiently.

shp (actual) = shp (design at STP) • d

shp (actual) = 1.75 • 0.85 = 1.5 hp

- If after installation we measure the SPh, what pressure would we expect to measure?

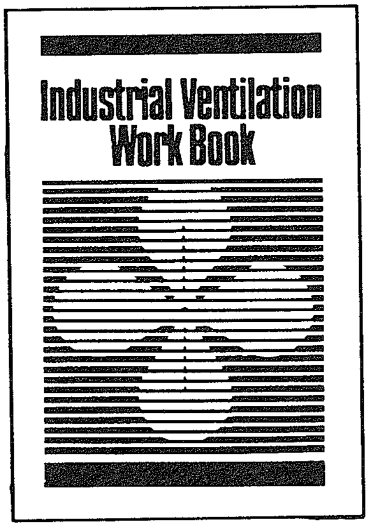
SPh (actual) = SPh (STP) • d

= -0.65 • 0.85 = -0.55" w.g.

Chapter 21.
More Resources and Additional Study

Congratulations on finishing the *Workbook*. Did you know you could get a Certificate of Completion? CM and CEU points? See page 278 for Home Study information. To enroll, please use the Order Form at the back of this book.

Other workbooks. You might want to pursue study of other workbooks—the latest versions of the *Industrial Ventilation Workbook*, the *IAQ and HVAC Workbook,* or the *Industrial Hygiene Workbook.*



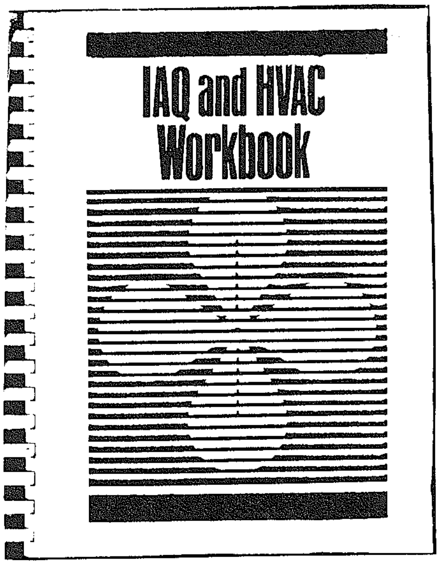
Industrial Ventilation Workbook

D. Jeff Burton, PE, CSP, CIH

This well-received 350 page self-study text is revised and expanded every two years. The *IV Workbook* takes the reader from introductory concepts through advanced materials in 20 chapters. It is reader-friendly and concentrates on practical applications; a complete section of charts and graphs is keyed to the text. The *IV Workbook* contains state-of-the-art discussions of hood and duct design, dilution ventilation, troubleshooting, fan selection, stack design, and much more. Written for safety and health professionals, the *Workbook* is an excellent companion to reference manuals and college textbooks.

A Comprehensive Home Study Course is available. See more information below.

ISBN 0-9623160-0-8. Original copyright 1992. 350 pages, $45. Use Order Form at back of book.



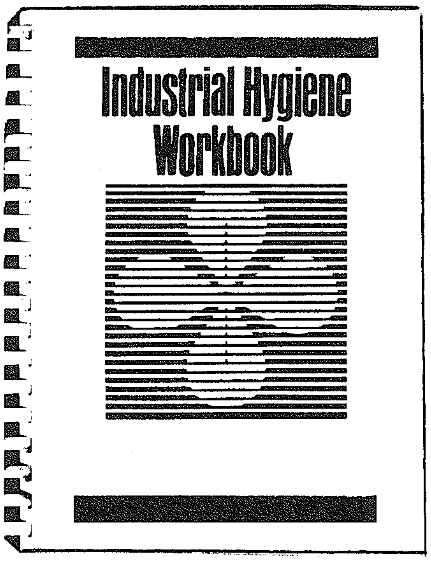
IAQ and HVAC Workbook
D. Jeff Burton, PE, CSP, CIH

New in 1993 and updated annually, the *IAQ and HVAC Workbook* replaces the highly successful *Indoor Air Quality Workbook. The IAQ and HVAC Workbook* is written in simple, understandable terms. Twenty one chapters cover:

- An overview of IAQ issues
- Investigation techniques
- Management of IAQ, management control strategies
- Air contaminants: microorganisms, aerosols, reactive chemicals, volatile organic chemicals, radon
- How building air handling systems work
- Air behavior and principles of ventilation
- Fans, air intakes, and HVAC ductwork
- Testing, commissioning, and troubleshooting HVAC systems
- How to read plans and specifications
- Application of the ASHRAE 62-1989 standard on IAQ
- Government standards and codes; government activities
- How to handle non-standard conditions

This reader-friendly workbook provides 7 charts, 9 forms, 28 checklists, references, a glossary, and an index. A **home study** course based on the workbook is available.

ISBN 0-9623160-7-5. (C) 1993; 335 pages; $45. Available from IVE, AIHA, ACGIH, ASHRAE, ASSE, NSC, and others.



Industrial Hygiene Workbook
D. Jeff Burton, PE, CIH, CSP

The *IH Workbook* contains all the facts about industrial hygiene in 23 sections. It is updated and reprinted every 12-18 months.

Topics include history, math and statistics, chemistry, physiology and anatomy, toxicology, occupational medicine, laws, codes, standards, air sampling, methods of control, ventilation, respiratory protection, PPE, IAQ, air pollution, ergonomics, heat and cold stress, noise, radiation, safety, and others.

Each section provides a short overview of the topic, a list of facts and concepts to know, calculation procedures, exercises, and multiple-choice questions to test your knowledge. To make learning and memorizing easy, the text is arranged in a two column format (key words on the left, what you need to know on the right).

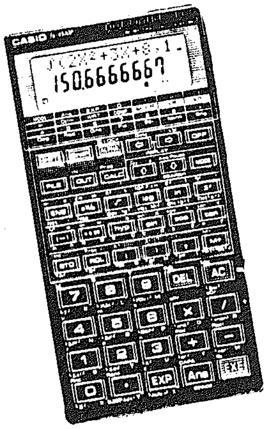
ISBN 0-9623160-9-1, 350 pages.Price, each, $45.00. See Order Form at back of workbook.

Home Study. Intensive home study course based on the *IH Workbook* are available from AIHA and IVE.

Calculator-aided calculation systems. I routinely use pre-programmed calculators in my work and in my courses. The calculator is very useful because it takes the mundane work out of the process, it is very fast, it keeps things accurate, and you don't have to remember the formulas!

As of January 1993 there were three versions available--one for each of the ventilation workbooks.

For the *Lab Ventilation Workbook,* the new CAD calculation package (priced at $139) is the most powerful aid on the market in its price class. The package includes a pre-programmed Casio FX-4500P calculator, instructions, sample calculations, and worksheets.



Using twelve programs, the Lab CAD system estimates:

- density correction for non-standard air conditions for all calculations
- dimensions and areas of round ducts
- velocity and volume flow rates in round or rectangular ducts
- volume flow rate from Ce and SPh
- emission rates for solvents and gases
- required dilution ventilation flow rates
- duct design using VP method
- brake horsepower
- losses in a duct using loss factors

For the *IAQ and HVAC Workbook,* the new IAQ CAD calculation package (priced at $139) is the only such aid on the market. The package includes a pre-programmed Casio FX-4500P calculator, instructions, sample calculations, and worksheets.

Using fifteen programs, the IAQ CAD system estimates:

- density correction for non-standard air conditions for all calculations
- dimensions and areas of round and rectangular ducts,
- velocity and volume flow rates in round or rectangular ducts
- emission rates for solvents and gases
- required dilution ventilation flow rates
- natural volume flow rates due to wind
- natural volume flow rates due to temperature differences

- air changes per hour given the volume flow rate,
- air changes per hour through the decay of CO_2
- the percent outdoor air (OA) from air temperature and CO_2 measurements
- changes in a ventilation system due to a change in fan speed using fan laws

For the *Industrial Ventilation Workbook,* the pre-programmed IV CADD calculator is marvelous. It easily and quickly performs complex design calculations for industrial duct design. The programs select proper duct diameters, adjust for roughness, estimate all losses, balance junctions, estimate correct duct diameter during resizing, and determine total system static pressure needs. Finally, it estimates fan total pressure and horsepower requirements. Best of all, it is easy to use and simple to learn.

Tailored courses. If you would like to provide a tailored course of instruction at your place of employment, please contact us at 2974 So. 900 East, Bountiful, Utah 84010. Telephone 801-298-8996.

Management education. We have available a management-oriented slide-tape program which describes ventilation in lay terms. It provides an excellent presentation for management safety meetings, maintenance training meetings, and so forth. Please see contact us for information.

Basic Home Study Courses for recertification points. We have a Lab Ventilation Home Study Course which uses this Workbook as its basic material. Successful completion of the course provides:

- a certificate of completion
- evidence sufficient to claim 4 recertification points for maintenance of certification (ABIH); 3.5 CEUs for CSPs
- a structured way of study
- a good feeling of accomplishment

Course materials consist of a copy of this workbook, course instructions, a final exam, and mailing materials. When the student completes the workbook, s/he takes the final exam and sends both the workbook and the final exam to us for review and grading. The workbook, the exam, and a Certificate of Completion are then sent to the student.

To complete the course the student must have successfully completed the workbook and passed the exam with a score of 80% or better. If the work is unsatisfactory, or if the exam has been failed, all materials are returned to the student for corrective action. Students have three chances to complete the course. Points are claimed in the year in which the Certificate is issued.

Comprehensive Home Study Courses. We have two comprehensive courses: *Fundamentals of Industrial Ventilation* and *Fundamentals of IAQ/HVAC.*

Features of the *Fundamentals of Industrial Ventilation* course include:

- Most cost effective training available
- Custom designed for easy independent study
- Created by an expert in the field
- Covers all fundamental aspects
  Eight parts (seven lessons and a final exam)
- Adoptable for either group or individual study
- Ongoing feedback shows what you've learned
- Available through your association
- Certificate of Completion at conclusion of course
- Complete package of learning materials
- Video tape explains complex materials
- *Industrial Ventilation Workbook,* 2nd E.
- *Industrial Ventilation -- A Manual of Recommended Practices,* 21st E.
- Preprogrammed Casio FX 4500P calculator and handbook (not shown)
- A 160-m video tape
- *Student Lesson Guide*
- Certificate of Completion
- Useful handout materials and the Final Exam

Materials. After enrolling in the course, you will receive a box from IVE with all the materials necessary to get started. You will be assigned a student number and an enrollment date.

Modules. The course is divided into eight modules—seven lessons and a final exam. All lesson materials are found (or will be eventually placed) in your *Student Lesson Guide,* a convenient three-ring binder.

Approach. Each lesson consists of required reading, watching the video tape, working problems in the *Workbook* and with the preprogrammed calculator, and taking an interim Lesson Test. Interim Lesson Tests are submitted to IVE for review and comment. After several weeks, they will be returned to you. In the meantime, you may proceed with the next lesson. You may call IVE at any time for help.

Final Exam. After completing all the lessons, you will receive a final exam. The finished final exam and competed workbook are returned to IVE for grading and comment. You will receive your graded materials and your Certificate after a few weeks.

Time. The average student takes about 60 hours of study to complete the course. (If you are new to the field, it may take longer.) Your Final Exam must be submitted within two years of enrollment date.

Similar features are found in the IAQ/HVAC comprehensive course.

To enroll or to obtain more information on IVE courses, use the **Order Form** on the last page of this book.

Appendix

More Information — page 282
Glossary — page 287
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Charts, Forms, and Checklists — page 297
Extra Charts for workbook exercises — page 339
Order Forms and Comment sheet — page 349

More Information

The following references are readable and informative. (Numbers are used to identify sources in the text. Missing numbers are references deleted during the latest workbook revision.)

Literature sources

1. L. DiBerardinis, et.al., *Guidelines for Laboratory Design,* 2nd Edition, Wiley-Interscience, New York, NY, 1993; excellent book details fundamentals of laboratory design.

2. ASHRAE, *Handbook of Fundamentals,* 1993, about 600 pages; one of four basic handbooks; see address under Standards; see particularly, Chapter 14, "Laboratories," 1991 *HVAC Applications Handbook.*

3. ACGIH, *Industrial Ventilation Manual,* 21st Edition, 1992; contact IVE, Inc., 2974 So. 900 East, Bountiful, Utah 84010; about 350 pages, $55.

4. D. Jeff Burton, IVE, Inc., *Industrial Ventilation Workbook,* 2nd Edition, 1992; contact IVE, Inc., 2974 So. 900 East, Bountiful, Utah 84010; 350 pages, $45; also available from ACGIH, AIHA, ASHRAE, and ASSE.

5. D. Jeff Burton, IVE, Inc., *IAQ and HVAC Workbook,* 1993; contact IVE, Inc., 2974 So. 900 East, Bountiful, Utah 84010; 340 pages, $45; also available from ACGIH, AIHA, ASHRAE, and ASSE.

6. SMACNA, *HVAC Systems — Testing, Adjusting, and Balancing,* 1983, about 250 pages; 4201 Lafayette Center Drive, Chantilly, VA 22021

7. ASHRAE Standard 62-1989 — *Ventilation for Acceptable Indoor Air Quality;* contact ASHRAE, 1791 Tullie Circle, NE, Atlanta, GA 30329; about 30 pages, $42.

8. P.E. McNall, A.K. Persily, "Ventilation Concepts for Office Buildings," *Ann. Am. Conf. Gov. Ind. Hyg.,* Vol 10, 1984, pp 49-58; overview of HVAC systems.

9. D. J. Wilson, "Ventilation Intake Contamination by Nearby Exhausts," APCA, *Transactions: IAQ in Cold Climates,* Pittsburgh, PA, 1985; "Contamination of Air Intakes from Roof Exhaust Vents," *ASHRAE Transactions 82,* 1976.

10. American Glovebox Society, *Guideline for Gloveboxes,* August, 1993, (Draft), about 100 pages; AGS, Standards Development Committee, 2150 W. 29th Ave., Suite 310, Denver, Colorado 80211; draft document describes various guidelines for the construction and use of glovebox hoods.

11. W. C. L. Hemeon, *Plant and Process Ventilation,* 1963, 470 pages, Industrial Press Inc, 200 Madison Ave, NY, NY 10016; out of print.

12. USDHHS, *Biosafety in Microbiological and Biomedical Laboratories,* 1988, HHS Publ. No. (NIH) 88-8395; for sale by the USGPO, Washington, DC 20402.

13. J. Baum, L. DiBerardinis, "Designing Safety in the Laboratory," Chapter 15 of the book *Improving Safety in the Laboratory*; John Wiley and Sons, NY, NY, 1990.

14. N. V. Steere, Editor, *Handbook of Laboratory Safety,* CRC, 1976; see pages 141-176, "Ventilation of Laboratory Operations," "Exhaust Systems," "Hoods for Science Laboratories," and "Air Conditioning for Laboratories."

15. NFPA 45 — *Fire Protection for Laboratories using Chemicals,* 1986; contact NFPA (address shown on next page).

16. NFPA 30 — *Flammable and Combustible Liquids Code.*

17. NFPA 90A — *Standard for the Installation of Air Conditioning and Ventilating Systems.*

18. NFPA 91 — *Standard for the Installation of Blower and Exhaust Systems for Dust Stock and Vapor Removal or Conveying.*

19. ASHRAE Standard 110 — *Method of Testing Performance of Laboratory Fume Hoods;* contact ASHRAE, 1791 Tullie Circle, NE, Atlanta, GA 30329; little used standard under revision as of November 1993.

20. EPA — *Standard Specification for Laboratory Fume Hoods*; contact EPA, Chief, FERPB, PM-215, Washington DC 20460.

21. SAMA — *SAMA Standard for Laboratory Fume Hoods,* December 1975, 1980. (Officially withdrawn; see Chapter 12, this *Workbook.*)

22. K. Evertt and D. Hughes, *A Guide to Laboratory Design,* 1981, Butterworths, London; see Chapters 6-8, "Laboratory Ventilation," "Fume Extraction and Dispersal," and "Laminar Air-flow Clean Rooms and Work Stations."

23. NRC, *Prudent Practices for Handling Hazardous Chemicals in Laboratories,* National Academy Press, Washington DC, 1983, see Section I.h, "Laboratory Ventilation."

24. D. C. Walters, Editor, *Safe Handling of Chemical Carcinogens, Mutagens, Teratogens and Highly Toxic Substances, 1980,* Volume 1, Ann Arbor Science, Ann Arbor Michigan; see Chapter 4, "Design and Operation of a Hazardous Materials Laboratory."

25. OSHA — 29 CFR 1910.1450 *Occupational Exposures to Hazardous Chemicals in Laboratories,* May 1, 1990; 200 Constitution Ave, NW., Washington, DC 20210

26. L. M. Woodrow, "An Evaluation of Four Quantitative Laboratory Fume Hood Performance Tests Methods," LANL, LA-11143-T, UC-41, November 1987, 207 pages.

27. NRC — *US NRC Regulatory Guides 8.23 and 8.24,* 1717 H Street, Wash DC 20555

28. K. J. Caplan and G. W. Knutson, “Laboratory Fume Hoods: A Performance Test,” *ASHRAE Transactions*, 84, Part 1, 1978. (10); “Influence of Room Air Supply on Laboratory Hoods,” *AIHA Journal* 43(10), pp 738-746, 1982. (27); “A Performance Test for Laboratory Fume Hoods,” *AIHA Journal* 43(10), pp 722-737, 1982.

29. G. W. Knutson, “Effect of Slot Position on Laboratory Fume Hood Performance, HPAC 56(2), pp 93-96, 1984.

30. R.I. Chamberlain and J.E. Leahy, “Laboratory Fume Hood Standards Recommended for the U.S,” EPA Contract No. 68-01-4661, 1978, EPA, 401 M Street, SW Washington DC 20460.

31. R. C. Peck, “Validation of a Method to Determine a Protection Factor for Laboratory Hoods,” AIHA Journal, 43(8), pp 596-601, 1982.

32. G. S. Nelson, “Laboratory Fume Hood Design, Evaluation, Modification, and Repair,” October, 1974, OSHO, Texas A&M University, College Station, Texas 77843; 140 pages.

33. American Chemical Society, *Safety in the Academic Laboratories,* 5th Edition, 73 pages, 1990; available from ACS, 1155 16th St., Washington, DC 20036; an excellent short book.

34. F. W. Dahan, “HVAC Systems for Chemical and Biochemical Laboratories,” HPAC, May 1986, pp 125-130.

35. NIOSH, *Pocket Guide to Chemical Hazards,* Cincinnati, Ohio, 1987; contact NIOSH, 4646 Columbia Pkwy, Cincinnati, Ohio 45226.

36. NAS, *Prudent Practices for handling Hazardous Chemicals in laboratories,* 1981, Washington DC.

37. ISA — *Recommended Environments for Standards Laboratories*, 1976, contact ISA, 67 Alexander Drive, RTP, North Carolina 27709.

38. ANSI — *Laboratory Ventilation,* Standard No. Z9.5,1992, contact AIHA, 2700 Prosperity Ave, Suite 250, Fairfax, VA 22031; premier standard for lab ventilation.

39. British Occupational Hygiene Society, *Controlling Airborne Contaminants in the Workplace,* Science Reviews Ltd., 1987, 175 pages, Chapter 7 deals with lab fume hoods; contact BOHS, 1 St. Andrews Place, Regents Park, London, NW1 4LB.

40. AFOSH Standard 161-2 — *Industrial Ventilation,* August 1977, 120 pages; contact the Department of the Air Force, Washington, DC 20330.

41. EPA — *EPA Standards - General Lab Fume Hood Specifications and Performance Testing Requirements*; contact EPA, 401 M Street, SW Washington DC 20460

42. UL, Inc. — *Standard for Safety: Laboratory Equipment,* 2nd edition, 1984; limited usefulness—fire and electrical safety.

46. USDA — *Laboratory Chemical Fume Hoods — Standards Manual 232.1,* 20 pages, 1981; contact the USDA, S&E, ASD, Washington DC 20250

47. NSF, *National Sanitation Foundation Standard No. 49 for Class II Biohazard Cabinetry (Laminar Flow),* 1992, Box 1468 Ann Arbor, MI 48105

48. Labconco, Personnel and Product Protection: A Guide to Biosafety Enclosures," 1992, Kansas City, MO; an excellent short introduction to the subject.

Agencies and Associations involved in Laboratory Ventilation

Additional background information may be obtained from the following sources:

60. ASHRAE (numerous books, articles, standards; journal)
1791 Tullie Circle, NE,
Atlanta, GA 30329

61. ACGIH (publications, reports, committee activity)
6500 Glenway #D-7,
Cincinnati, Ohio 45211

62. EPA (general publications on the subject, performance testing procedures, standards)
401 M Street, SW
Washington DC 20460

63. NEBB, National Environmental Balancing Bureau (list of certified HVAC balancing firms)
1385 Piccard Drive
Rockville, MD 20850

64. American Chemical Society, 1155 16th St., Washington, DC 20036 (misc publications)

65. AIHA (list of industrial hygiene consultants, laboratory accreditation, ANSI Z9 Secretariat, training courses)
2700 Prosperity Ave, Suite 250,
Fairfax, VA 22031

66. NIOSH (lists of publications, studies of laboratory health and safety, standards)
4646 Columbia Parkway
Cincinnati, Ohio 45226

67. SMACNA (publications, sheet metal, ductwork)
4201 Lafayette Center Drive
Chantilly, VA 22021

68. AMCA (fans and dampers; numerous publications)
30 W. University Drive
Arlington Heights, Ill 60004

69. ASSE (list of safety consultants, publications)
1800 East Oakton Street
Des Plaines, Ill 60018

70. NFPA (standards, publications)
1 Batterymarch Park
Quincy, Mass 02269

71. OSHA (regulations, publications)
201 Constitution Ave, NW,
Washington DC 21210.

72. CDC/Office of Biosafety (publications, information on biosafety cabinets)
Atlanta, Ga 30333 (phone 404-329-3883)

73. SAMA (publications)
225 Reinekers Lane, No. 625
Alexandria, VA 22314

74. NSF (information on biosafety hoods)
Box 1468
Ann Arbor, MI 48105

75. Chemtrec, (emergency assistance); associated with CMA
2501 "M" St., NW
Washington DC 20037

76. American Glovebox Society
2150 W. 29th Ave., Suite 310,
Denver, Colorado 80211

Major Equipment Manufacturers and Suppliers **(Alphabetical Order)**

80. Hamilton Industries, Two Rivers, Wisconsin 54241 (hoods, lab equipment).

81. Hemco, 111 Powell, Independence MO 64050 (lab equipment, hoods).

82. Kewanee, Box 5400, Statesville, NC 28677 (hoods, lab equipment).

83. Labconco Corporation, 8811 Prospect, Kansas City, Missouri 64132 (hoods, lab equipment).

84. Lab Fabricators Company, 1802 East 47th Street, Cleveland, Ohio 44103 (lab furniture and equipment, hoods)

85. Phoenix Controls Corporation, 83 Chapel Street, Newton, MA 02158 (VAV for lab fume hood and air supply controls)

Training Courses

90. AIHA, *Laboratory Ventilation* (3-day training course offered on periodic basis)
2700 Prosperity Ave, Suite 250
Fairfax, VA 22031.

91. ASHRAE (Various conferences and home study courses)
1791 Tullie Circle, NE,
Atlanta, GA 30329

92. IVE Inc. (Home study courses)
2974 So. 900 East,
Bountiful, Utah 84010

Glossary

A&E. The "architect and engineer." Generic term refers to designers of laboratory buildings and ventilation systems.

acceptable indoor air quality. Air in which there are no known contaminants at harmful levels as determined by appropriate authorities, *and* air with which 80% or more of the people do not express dissatisfaction.

acfm. Actual cubic feet per minute of gas flowing at existing temperature and pressure. (See also scfm)

ACGIH. The American Conference of Governmental Industrial Hygienists; association supports or produces TLV list, *Industrial Ventilation Manual,* bioaerosol documents.

ACH, AC/H. (air changes per hour), n. The number of times air is theoretically replaced during an hour.

AHU. (air handling unit). Refers to ventilation equipment in hvac systems.

Air conditioning. The process of treating air to meet the requirements of a conditioned space by controlling its temperature, humidity, cleanliness, and distribution.

Air density. (also weight density). The weight of air in lbs per cubic foot. Dry standard air at t = 70 degrees f, bp = 29.92 inch Hg has a density of w = 0.075 lbs/cu ft.

Anemometer. A device which measures velocity of air. Common types include the swinging vane and the hot-wire anemometer.

Area, A. The cross-sectional area through which air moves. Could be the cross-sectional area of a duct, a window, a door, or any space through which air moves. Units, square feet, sf.

Arrestance. A filter's ability to remove a coarse dust particle.

ASHRAE. (American Society of Heating, Refrigeration, and Air Conditioning Engineers). Primary association involved in IAQ problems and solutions.

Atmospheric pressure . The pressure exerted in all directions by the atmosphere. At sea level, mean atmospheric pressure is 29.92 inch Hg, 14.7 psi, 407 inch w.g., or 760 mm Hg.

Auxiliary air supplied hood . A hood in which air is delivered to the face of the hood to reduce room air consumption.

Bioaerosol. Suspensions in air of viruses, bacteria, fungi, pollen, and their non-viable components.

Biological safety cabinet . A special safety enclosure used to handle and contain biological materials.

Brake horsepower, bhp. The actual horsepower required to move air through a ventilation system against a fixed total pressure plus the losses in the fan. bhp = ahp • 1/ME, where ME is fan mechanical efficiency.

Branch. In a junction of two ducts, the branch is the duct with the lowest volume flow rate. The branch usually enters the main at some angle less than 90 degrees.

Bypass lab fume hood. A lab fume hood constructed such that as the sash closes, air is allowed to bypass the hood face through another opening, usually above the sash. The bypass hood provides for a reasonably constant face velocity and hood static pressure.

Canopy hood, (also, receiving hood). A one- or two-sided overhead hood which receives rising hot air or gas.

Capture velocity. The velocity of air induced by a hood to capture emitted contaminants external to the hood.

Coefficient of entry, Ce . A measure of the efficiency of a hood's ability to convert static pressure to velocity pressure; the ratio of actual flow to ideal flow.

Coils. Heating and cooling heat exchanger which either adds heat or takes heat from the air in an hvac system.

Damper. A device installed in a duct to control air volume flow rate.

Diffuser. An outlet designed to distribute air in varying directions and planes.

Dilution ventilation (also, general exhaust ventilation). A form of exposure control which relies on the dilution of airborne contaminants in workplace air.

Ductless lab hood. A hood which filters exhaust air and returns it to the lab environment.

Economizer cycle, economizer equipment. The use of up to100% outside air (OA) during favorable weather conditions, e.g., temperatures 55-70° F; may cause problems when ambient air has high humidity.

Entry loss. see Hood entry loss or branch entry loss

evase. (Eh-va-say) a cone shaped exhaust stack which recaptures static pressure from velocity pressure.

Exhaust collar. The connection between the exhaust duct and the fume hood through which exhaust air passes.

Face velocity. The rate of flow per square area (cubic feet per minute per sq ft of hood open face area), or the velocity (feet per minute) of air moving through the open area of a lab fume hood.

Fan. A mechanical device which physically moves air and creates static pressure.

Fan laws. Relationships which describe theoretical, mutual performance changes in pressure, flow rate, rpm of the fan, horsepower, density of air, fan size, and sound power.

Fan curve. A curve relating pressure vs. volume flow rate of a given fan at a fixed fan speed (rpm).

Friction loss. The static pressure loss in a system due to friction between moving air and the duct wall; expressed as inches w.g. per 100 feet, or fractions of VP per 100 feet of duct (mm w.g./meter; K/meter).

Fume cupboard. British term for laboratory fume hood.

Gauge pressure. The difference between two absolute pressures, one of which is usually atmospheric pressure; viz, inches water *gauge* (in w.g.).

General exhaust. (See dilution ventilation.)

Glove box lab hood. An enclosed, six-sided hood with arm-length gloves provided at the side of the hood for access. An air-lock pass-through port is often provided to insert and remove materials from the hood.

Grille. A louvered or perforated face over an opening in an HVAC system.

Head. Pressure. "The head is one inch w.g."

Hood. A device which encloses, captures, or receives emitted contaminants.

Hood entry loss, He . The static pressure loss, stated in inches w.g., when air enters a duct through a hood. The majority of the loss is usually associated with a vena contracta formed in the duct.

Hood static pressure, SPh. The sum of the duct velocity pressure and the hood entry loss; it is the static pressure required to accelerate air at rest outside the hood into the duct at duct velocity.

HVAC. Ventilation systems designed primarily for temperature, humidity, odor control, and air quality.

Indoor air quality, IAQ . The study, evaluation, and control of indoor air quality related to temperature, humidity, and airborne contaminants.

Inches of water, "inch w.g." A pressure term. One inch of water is equal to 0.0735 inches of mercury, or 0.036 psi. Atmospheric pressure at standard conditions is 407 inches w.g. (water gauge.)

Industrial ventilation, IV. The equipment or operation associated with the supply or exhaust of air, by natural or mechanical means, to control occupational hazards in the industrial setting.

Infiltration. Air leakage into a space through cracks and interstices, and through ceilings, floors, and walls.

Laboratory. The net assignable area in which diverse mechanical services and special ventilation systems are available to control emissions and exposures from chemical operations.

Laboratory hood. A ventilated enclosure designed to capture, contain, control, and remove fumes, gases, vapors, and particles generated within the enclosure.

Laboratory module. A basic unit of space usually accommodating a two-person laboratory operation.

Laboratory ventilation. Air moving systems and equipment which serve laboratories.

Laminar flow, also streamline flow. Air flow in which air molecules travel parallel to all other molecules; flow characterized by the absence of turbulence.

Local exhaust ventilation. An industrial ventilation systems which captures and removes emitted contaminants before dilution into the workplace ambient air can occur.

Loss. Usually refers to the conversion of static pressure to heat in components of the ventilation system, viz., "the hood entry loss."

Make-up air. (See replacement and compensating air).

Manometer. A device which measures pressure difference; usually a u-shaped glass tube containing water or mercury.

Microorganism. A microscopic organism, usually a bacterium, fungus, or protozoan.

Minimum transport velocity, MTV. The minimum velocity which will transport particles in a duct with little settling; the mtv varies with air density, particulate loading, and other factors.

Natural ventilation. The movement of outdoor air into a space through intentionally provided openings, such as windows, doors, or other non-powered ventilators, or by infiltration.

Occupied zone. The region within an occupied space between the floor and 72" above the floor and more than 2 feet from the walls for fixed air conditioning equipment. (From ASHRAE Standard 55-1992.)

Odor. A quality of gases, vapors, or particles which stimulates the olfactory organs; typically unpleasant or objectionable.

Outdoor air (OA). "Fresh" air mixed with return air (RA) to dilute contaminants in the supply air (SA).

Perchloric acid fume hood. A fume hood constructed with special materials and water-wash capabilities so as to provide safe operating conditions using perchloric acid, perchlorates, or the reagents which form flammable or explosive compounds with organic materials.

Pitot tube. A device used to measure total and static pressures in an air stream.

Plenum. A low-velocity chamber used to distribute static pressure throughout its interior.

Pressure drop. The loss of static pressure across a point; for example, "The pressure drop across an orifice is 2.0 inch w.g."

Register. A combination grille and damper assembly.

Relative humidity, rh. The ratio of water vapor in air to the amount of water vapor air can hold at saturation. A rh of 100% is about 2.5% water vapor in air, by volume.

Replacement air. (Also, compensating air, make-up air.) Air supplied to a space to replace exhausted air.

Respirable particles. Those particles in air which penetrate into and are deposited in the nonciliated portion of the lung.

Return air. Air which is returned from the primary space to the fan for recirculation.

Sash. A moveable panel or door set in the hood entrance to form a protective shield and to control the face velocity of air into the hood.

Sensible heat. Heat manifested to body senses; the heat which fixes the temperature of air; heat which, when added to air, changes its temperature.

Sick building syndrome. Usually refers to a class of complaints or symptoms (e.g., discomfort, headache, URT irritation) seen in IAQ episodes.

scfm, standard cubic feet per minute. Air flow rate at standard conditions: dry air at 29.92 inches Hg gauge, 70 degrees F.

Slot velocity. The average velocity of air through a slot. It is calculated by dividing the total volume flow rate by the slot area; usually Vs = 2000 fpm.

Stack. The device on the end of a ventilation system which disperses exhaust contaminates for dilution by the atmosphere.

Standard air, standard conditions. Dry air at 70 degrees F, 29.92 inch Hg. (ACGIH)

Static pressure, SP. The pressure developed in a duct by a fan; sp exerts influence in all directions; the force in inches of water measured perpendicular to flow at the wall of the duct; the difference in pressure between atmospheric pressure and the absolute pressure inside a duct, cleaner, or other equipment.

Suction pressure. See static pressure. (Archaic. Refers to static pressure on upstream side of fan.)

Tight building syndrome. Commonly related to problems associated with buildings designed and operated at minimum outdoor air supply, or poor distribution. See also sick building syndrome.

Total pressure, TP. The pressure exerted in a duct as the sum of the static pressure and the velocity pressure; also (incorrectly) sometimes called "impact pressure," and "dynamic pressure."

Total suspended particulate matter. The mass of particles suspended in a unit volume of air (typically one cubic meter) when collected by a high-volume sampler.

Turbulent flow. Air flow characterized by transverse velocity components as well as velocity in the primary direction of flow in a duct; mixing velocities.

TWA (time-weighted average). The average exposure at the breathing zone, measured usually over an entire shift.

Variable air volume, VAV. In HVAC system, the supply air volume is varied by dampers or fan speed controls to maintain the temperature; in hoods, the exhaust air is varied to reduce the amount of air exhausted.

Velocity, V. The time rate of movement of air; feet per minute.

Velocity pressure, VP. The pressure attributed to the velocity of air.

Volume flow rate, Q. The quantity of air flowing in cubic feet per minute, cfm, scfm, acfm.

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Charts, Forms, and Checklists (originals)

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2	Consensus Standards Summary
3	Useful conversion factors
4	Properties of common solvents and gases
5	Round duct flow nomograph
6	Air Density correction factor, d
7	Common Loss Factors: Elbows and Branch Entries
8	Common Loss Factors: Duct friction and hoods
Forms	
1	Laboratory chemical hazard-potential determination
2	Laboratory walk-through survey worksheet
3	Face velocity measurement worksheet
4	Pitot tube traverse worksheet
5	Lab fume hood deficiency report form
6	Duct design worksheet (IVE, Inc.)
Checklists	**Investigations**
1	Laboratory problem investigation checklist
2	Checklist for initial walkthrough survey of a lab
3	Checklist for safety and housekeeping
4	Checklist for interview with lab supervisor
5	Checklist for in-depth on-site investigation of a building in which a lab is located (where complaints originate from non-lab workers)
6	Laboratory building information checklist
	Controls
7	Laboratory air screening checklist
8	Checklist for avoiding legal actions
9	Building owners documentation and programs
10	Checklist for minimizing lab ventilation problems
	Ventilation
11a	Basic information checklist for supply and HVAC systems
11b	Basic information checklist for exhaust systems
12	Checklist for reviewing laboratory plans and specifications
13	Lab users checklist of the ventilation in a lab
14	Inspection checklist for lab ventilation systems
15	Lab HVAC and air supply troubleshooting checklist
16	Lab fume hood fan specification criteria
17	Lab fume hood fan maintenance checklist
	Emergencies
18	Information and Emergency Phone Numbers
	Specifications and Standards
1	Sample specifications for a lab fume hood
2	Sample ventilation paragraphs, management plan (Chemical Hygiene Plan)

Chart No. 1
Ventilation Terms and Units

Term	Definition	US units	SI units	Chapter*
A	Area	sq ft	sq meters	3
C	Duct circumference	inches	meters	3
D	Duct diameter	inches	meters	3
Q	Volume flow rate	cfm	cu meter/sec	3
V	Velocity	fpm	m/sec	3
T	Temperature (e.g., T_{OA})	°F, °R	°C, °K	3, 20
d	Density Correction Factor	unitless	unitless	3, 20
w	Air weight density	lbs/cu ft	kg/cu meter	3
TP	Total Pressure	inches w.g.	mm w.g.	3
SP	Static Pressure	inches w.g.	mm w.g.	3
VP	Velocity Pressure	inches w.g.	mm w.g.	3
N	Air changes per hour	ac/hr	ac/hr	16
q	Vapor generation rate	cfm	cu. m/sec	16
Q_d	Dilution Q (also, Q_{OA})	cfm	cu. m/sec	16
K_m	Air mixing factor (also, K_{eff})	unitless	unitless	5, 16
C	Concentration (e.g., C_{RA})	ppm	ppm	16
C_a	Acceptable concentration	ppm	ppm	16
MW	Molecular weight	unitless	unitless	16
s.g.	Specific gravity	unitless	unitless	16
Vol	Room Volume	cubic feet	cubic meters	16
t	time	minutes	seconds	16
G	Generation rate	cfm	cu m/sec	16
FTP	Fan Total Pressure	inches w.g.	mm w.g.	18
n	Fan rotational speed, rev/min	rpm	rpm	18
ME	Fan mechanical efficiency (0-1)	unitless	unitless	18
K_{dl}	Drive loss factor (>1)	unitless	unitless	18
shp	Shaft horsepower	hp	kw	18
rhp	Rated horsepower	hp	kw	18

*Major chapter in which the term is explained.

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Chart No. 2
Consensus Standards Summary

Topic	Name (often abbreviated)	Organization	Number
Labs	Laboratory Ventilation	ANSI	ANSI Z9.5 - 1992
Testing	Testing Performance of Lab Fume Hoods	ASHRAE	Standard 110 - 1994?
General	Ventilation for Acceptable Indoor Air Quality	ASHRAE	ASHRAE 62 - 1989
	The Ventilation Directory	NCSBCS	Summary of standards
	Fire Protection for Laboratories using Chemicals	NFPA	NFPA 45 - 1986
Bio-aerosols	Guidelines for the Assessment of Bioaerosols in the Indoor Environment	ACGIH	ACGIH Publication
	Class II Cabinets	NSF	Standard No. 49
Comfort	Thermal Comfort	ASHRAE	ASHRAE 55 - 1981
Air filters	Filter testing methods	ASHRAE	ASHRAE 52 - 1992
	Test Performance of Air Filter Units	UL	ANSI/UL 900 - 1982
HVAC	Duct standards	SMACNA	SMACNA (various)
	Guideline for the Commissioning of HVAC Systems	ASHRAE	Guideline 1-1989
	Recommended standards for duct cleaning	NADCA	Various standards
	Standards and practice for TAB	NEBB	Various standards
Fans	Testing fan sound power	ASHRAE	ASHRAE 68 - 1986
	Standards Handbook	AMCA	AMCA 99-83 + others

Standards Associations	
ACGIH	American Conference of Governmental Industrial Hygienists, 6500 Glenway #D-7, Cincinnati, Ohio 45211
ANSI	American National Standards Institute; Contact AIHA (ANSI Z.9 Secretariat) 2700 Prosperity Ave, Suite 250, Fairfax, VA 22031
ASHRAE	American Society of Heating, Refrigerating and Air-conditioning Engineers, Inc., 1791 Tullie Circle, NE., Atlanta, GA 30329 (Various standards related to ventilation system design, operation, and maintenance.)
NADCA	National Air Duct Cleaners Association, 1518 K St NW Suite 503, Wash, DC 20005
NCSBCS	NCSBCS, 505 Huntmar Park Drive, Suite 210, Herndon, VA 22070
NEBB	National Environmental Balancing Bureau, 4201 LaFayette Center Drive, Chantilly, VA 22021
NFPA	National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02269
NSF	Box 1468, Ann Arbor, MI 48105 (Information on biosafety hoods.)
SMACNA	1385 Piccard Drive, Rockville, MD 20850
UL	Underwriter's Laboratories, 333 Pfingsten Road, Northbrook, IL 60062

See Chapter 12 for more detailed information. (c) 1994 D. Jeff Burton

Chart No. 3
Useful Conversion Factors

To convert	into	Multiply by
Atmospheres	inches Hg	29.92
	inches w.g.	407
	psi	14.7
	bars	1.0133
	mm Hg	760
BTU/min	hp	0.02356
	kw	0.01757
Celsius	Fahrenheit	(°C x 9/5 + 32)
	Kelvin	(°C + 273)
cubic feet	cubic inches	1728
	cubic meters	0.02832
	gallons	7.4805
	liters	28.32
cfm	liters/sec	0.472
	cu meters/sec	4.72 x 10^{-4}
	lbs/min (STP)	0.075
circumference	diameter	0.3183
cubic meters	cubic feet	35.31
	gallons	264.2
	liters	1000
Fahrenheit	Rankine	(°F + 460)
	Celsius	(°F - 32 x 5/9)
Feet	centimeters	30.48
	meters	0.3048
	miles (stat)	1.894 x 10^{-4}
fpm	meter/sec	0.00508
	miles/hr	0.00136
horsepower	kw	0.7457
inches w.g.	atmospheres	2.458 x 10^{-3}
	inches Hg	0.07355
	psi	0.03613
	mm Hg	1.867

To convert	into	Multiply by
Kw	hp	1.341
Liters	cubic feet	0.03531
	cubic meters	0.001
	gallons	0.2642
meters	feet	32.81
	miles	6.214 x 10^{-4}
	inches	39.37
	yards	1.094
meters/sec	feet/min	196.8
	miles/hour	2.237
micrometer	meter	1 x 10^{-6}
miles	feet	5280
	kilometers	1.609
miles/hour	feet/min	88
milligrams	pounds	2.205 x 10^{-6}
mm Hg	inches w.g.	0.5355
	psi	0.0193
	inches Hg	0.0394
pounds	grams	453.6
	ounces	16
	grains	7000
pounds/cu ft	kgs/cu meter	16.02
psi	atmospheres	0.068
	inches Hg	2.036
	inches w.g.	27.68
	mm Hg	51.70
sq ft	sq meters	0.093
	sq inches	144
sq meters	sq feet	10.76

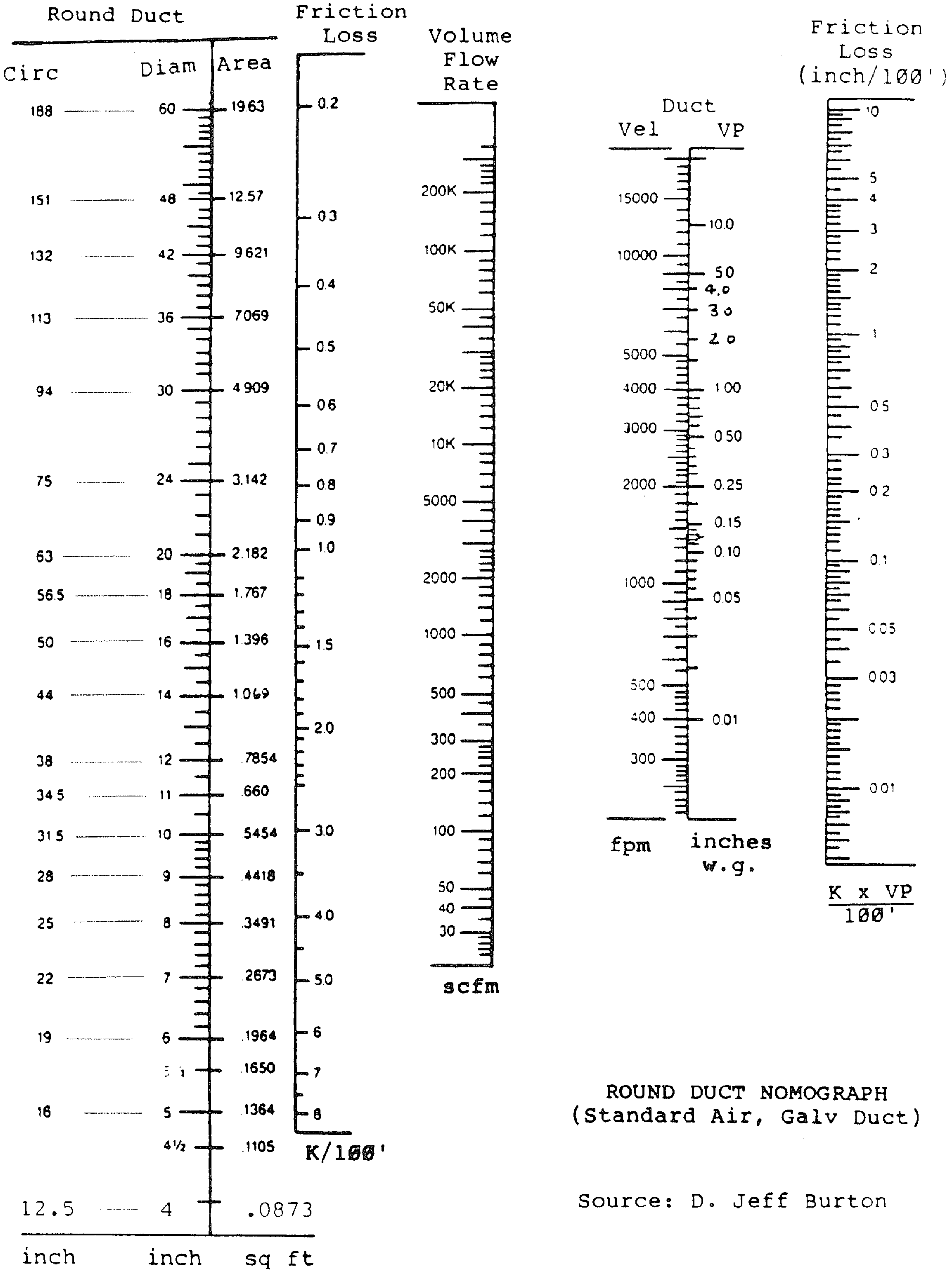
Chart No. 4
Properties of Common Solvents and Gases

	Molecular Wt	Specific Gravity	Explosion Limit		TLV*	IAQ-LV*
Solvent/vapor	MW	(re: water)	LEL %	UEL	(ppm)	(ppm)
Acetaldehyde	44.1	0.821	4.0	57	25	0.1 TLV
Acetic Acid	60	1.049	na	na	10	0.1 TLV
Acetone	58.1	0.792	2.7	10.1	750	0.1 TLV
Benzene	78.1	0.879	1.4	7.1	0.1	0.1 TLV
Cresol	108.1	1.05	1.4	na	5	0.1 TLV
Carbon Tet	153.8	1.596	na	na	5	0.1 TLV
Ethyl Acetate	88.1	0.901	2.2	11.4	400	0.1 TLV
Ethyl Alcohol	46.1	0.789	3.3	18.9	1,000	0.1 TLV
Ethylene Glycol	62.1	1.12	3.2	na	50	0.1 TLV
Freon TF solvent	187.4	1.57	na	na	1,000	0.1 TLV
Isopropyl alcohol	60.1	0.785	2.0	11.8	400	0.1 TLV
Kerosene	180	0.80	0.7	5	na	na
Methanol	32	0.792	6.7	36.5	200	0.1 TLV
MEK	72.1	0.806	1.8	11.5	200	0.1 TLV
MIBK	100.1	0.801	na	na	50	0.1 TLV
Mineral spirits	>100	0.80	0.8	5	na	na
Naphtha (solvent)	90	0.7	0.8	5	200	0.1 TLV
Styrene monomer	104.1	0.903	1.3	6.7	50	0.1 TLV
Perchloroethylene	165.8	1.63	na	na	25	0.1 TLV
Toluene	92.1	0.866	1.3	6.7	50	0.1 TLV
1,1,1 TC Ethane	133.4	1.31	7	16	350	0.1 TLV
Trichloroethylene	131.4	1.466	na	na	50	0.1 TLV
Xylene	106.2	0.881	1.0	6.0	100	0.1 TLV

	Molecular Wt	Specific Gravity	Explosion Limits		TLV*	IAQ-LV*
Gas	MW	(re: air)	LEL %	UEL	(ppm)	(ppm)
Air	29	1.0	na	na	na	no odors
Butane	58.1	2.085	1.9	8.4	800	0.1 TLV
Carbon Dioxide	44	1.53	na	na	5,000	1000
Carbon Monoxide	28.1	0.968	12.5	74.2	25	9
Chlorine	70.9	3.21	na	na	0.5	0.1 TLV
Formaldehyde	30	1.08	na	na	0.3	0.1
Hydrogen Chloride	36.5	1.27	na	na	5	0.1 TLV
Hydrogen Sulfide	34.1	1.19	4.3	45.5	10	0.1 TLV
Nitrogen Dioxide	46.0	1.448	na	na	3	0.3
Ozone	48	1.658	na	na	0.1	0.05
Sulfur Dioxide	64.1	2.264	na	na	2	0.14

* "TLV" is 1992-93 ACGIH BZ airborne limits for places of employment.
"IAQ-LV" is ASHRAE data or other typical targets for general indoor environments.

Chart No. 5
Round Duct Air Flow Nomogram



ROUND DUCT NOMOGRAPH
(Standard Air, Galv Duct)

Source: D. Jeff Burton

Chart No. 6
Air Density Correction Factor, d*

Elevation	feet		0	1000	2000	3000	4000	5000	6000	7000
	meters		0	305	610	915	1220	1525	1830	2135
----- or -----										
Barometric Pressure	mm Hg		760	733	707	681	656	632	608	587
	inch Hg		29.92	28.86	27.82	26.82	25.84	24.89	23.97	23.09
Air Temperature	°C	°F								
	-40	-40	1.26	1.22	1.18	1.14	1.09	1.05	1.01	0.966
	-18	0	1.15	1.11	1.07	1.03	0.998	0.959	0.921	0.882
	0	32	1.08	1.04	1.01	0.969	0.933	0.897	0.861	0.825
	21	70	1.00	0.966	0.933	0.900	0.866	0.833	0.799	0.766
	38	100	0.946	0.915	0.883	0.851	0.820	0.788	0.756	0.725
	66	150	0.869	0.840	0.811	0.782	0.753	0.723	0.694	0.665
	93	200	0.803	0.776	0.749	0.722	0.696	0.669	0.642	0.625

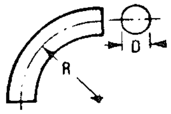
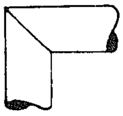
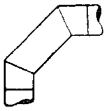
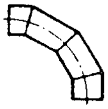
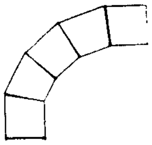
*("W" on the LV CAD calculator)

For more information, see Chapters 3 and 20

(c) 1994 D. Jeff Burton

Chart No. 7
Loss Factors: Elbows and Branch Entries

ELBOW LOSS FACTORS, K
(Round 90° ducts at STP)

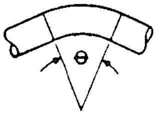
TYPE:	K Smooth Transition (1)	(2)	Mitre	3-piece	4-piece	5-piece
Round Duct *R/D						
0.50	--	0.80	1.20	1.15	1.10	0.90
0.75	--	--	--	0.60	0.55	0.50
1.00	--	0.35	--	0.45	0.40	0.38
1.25	0.55	0.30	--	0.42	0.38	0.33
1.50	0.39	0.27	--	0.39	0.34	0.28
2.00	0.27	0.24	--	0.41	0.33	0.28
2.5	0.22	0.24	--	--	0.37	0.30

* Notes: R = radius of curvature as number of duct diameters, radius to center-line of duct.

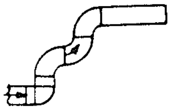
(1) and (2) above represent range of sources.

Loss Factor K includes friction loss

$SP_{loss} = K \times VP_d$.



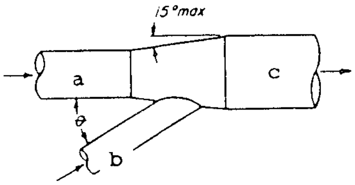
For angles < 90°, $K_\theta = \left(\frac{\theta}{90}\right) \times K_{90}$



For combined elbows in continuous ductwork:

$K_t = 1.25 \times$ (Sum of individual K factors)

BRANCH ENTRY LOSSES



θ	K
15	0.10
20	0.12
30	0.18
45	0.28
60	0.44
75	0.73
90	1.0

Insert K in Row 23

Loss occurs in branch b

Chart No. 8
Estimated Loss Factors: Lab Fume Hoods*

*For Row 17, correction for non galvanized duct: ***

Duct Material	Correction Factor, Cf or R*
Galvanized duct	1.0
Smooth fiberglass, Stainless steel, ABS and PVC plastic	0.8 - 0.9
Spiral wound galvanized	1.1
Any flex duct	2.5 - 2.8

For Row 20, duct entry loss (the so-called "hood entry loss"):*

K = 0.50 for straight takeoffs (no tapered entry to the duct from the hood plenum)

K = 0.25 for tapered takeoffs

K = 2.0 when Rows 5-11 are not used.

Typical Volume Flow rates: **Q = 80A to 120 A**, where A is hood face area (i.e., Face Velocities of 80-120 fpm.)

Typical duct velocities: **V_{duct} = 2000 fpm**. Higher velocities will be required for ducts carrying settleable aerosols.

Coefficient of Entry: **0.55-0.65** for low velocity hoods. When K = 2.0, Ce = 0.58.

For more detailed information, see Reference No. 4, *Industrial Ventilation Workbook.*

*Check with suppliers and manufacturers for actual numbers.

**Row numbers refer to Form No. 6 of the Workbook. For LV CAD calculator, see instructions.

Form No. 1
Laboratory Chemical Hazard-Potential Determination

Evaluator Name______________ Date __________ Phone number________________

Lab Contact Name__________Location________ Phone number__________

Name of chemical________________________CIS______________________

Type______________________________________ MSDS________________

Hazard potential (toxicity, fire)____

____

Describe physical characteristics:____________________________________
Melting Point__________Boiling Point__________Vapor Pressure__________
Physical State_________Particle Size__________Solubility__________________
Routes of potential exposure__________________TLV/PEL________________
Chemical Hazard Class____
Describe potential exposures:____

____

Quantity of chemical used_________________ Dilution Ratios____________
Frequency of exposure________________Duration_____________________

Describe administrative controls:______________________________________

____

Lab Fume Hood____

____

Personal protection ____

Describe required changes:____

For explanatory information, see Chapters 4, 9 1994 D. Jeff Burton

Form No. 2
Laboratory Walk-through Survey Worksheet

Name______________________ Date__________________________

Contact____________________ Location________________________

Phone_____________________ Lab No. ______________________

Potential Problem	Yes/No	Comments
☐ Lab worker complaints		
☐ Hazardous chemicals being used		
☐ Corrosion of walls/equipment		
☐ Lack of replacement air		
☐ Inadequate air distribution in lab		
☐ Pressure difference between rooms		
☐ Poorly located air supply registers		
☐ Drafts at hood face		
☐ Detectable odors in lab		
☐ Temperature too warm		
☐ Temperature too cold		
☐ Humidity too high (>60%)		
☐ Humidity too low (<30%)		
☐ Dirty, organic debris		
☐ Visible mold, slime		
☐ Water damaged furnishings		
☐ Poorly stored chemical containers		
☐ Chemicals open on bench		
☐ Deteriorated asbestos		
☐ Poor maintenance of lab hood		
☐ Uncontrolled equipment emissions		
☐ Free standing fans in lab		
☐ Lab fume hood inoperable		
☐ Poor lab hood work practices		
☐ Poor work practices, general		
☐ Poorly located loading docks		
☐ Tobacco/food in lab		

For explanatory information, see Chapters 19, 10, and 4 1994 D. Jeff Burton

Form No. 3
Face Velocity Measurement Worksheet

FACE VELOCITY WORKSHEET

Date ____________ Time ____________ ____________

Temp ____________ B.P. ____________ ____________

Vel. Corr. ______ Name ______________________________

Equipment ______ Location ___________________________

No.	Vel	No.	Vel	No.	Vel
1		11		21	
2		12		22	
3		13		23	
4		14		24	
5		15		25	
6		16		26	
7		17		27	
8		18		28	
9		19		29	
10		20		30	

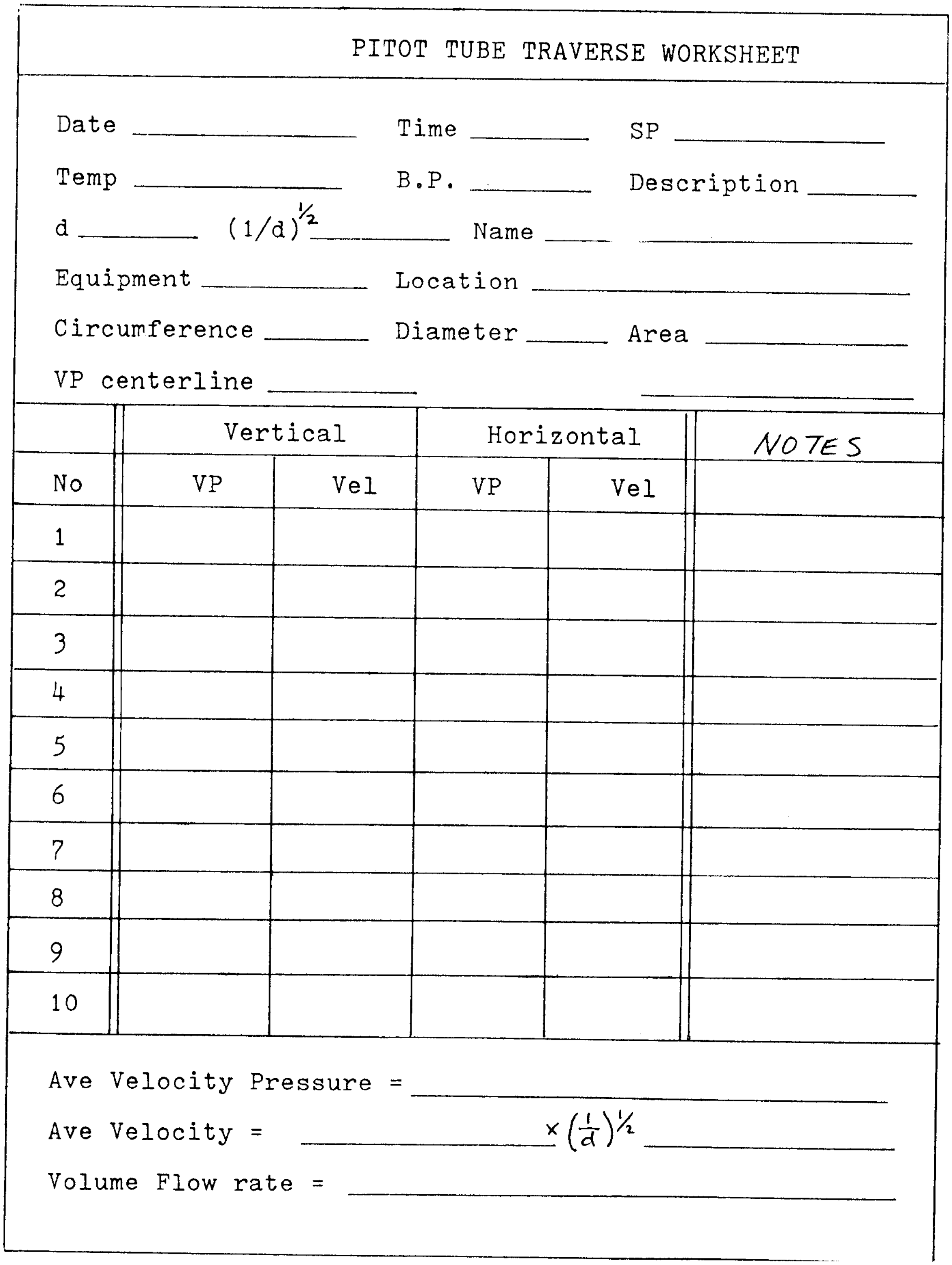
Ave Velocity = ____________

Hood Face Area = ____________

Volume Flow rate = ____________

____

Form No. 4
Pitot Tube Traverse Worksheet



PITOT TUBE TRAVERSE WORKSHEET

Date ____________ Time ________ SP ____________

Temp ____________ B.P. ________ Description ________

d ________ $(1/d)^{1/2}$ ____________ Name ______ ____________

Equipment ____________ Location ____________

Circumference ________ Diameter ______ Area ____________

VP centerline ____________ ____________

	Vertical		Horizontal		NOTES
No	VP	Vel	VP	Vel	
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

Ave Velocity Pressure = ____________

Ave Velocity = ____________ $\times \left(\frac{1}{d}\right)^{1/2}$ ____________

Volume Flow rate = ____________

Form No. 5
Lab Ventilation Deficiency Report Worksheet

Bldg________ Room ________ Hood
Number ____________ Fan Number ______
Date__________ Investigator/Reporter ______

Page 1

Notes:

Management
( ) No local cognizant person
( ) Lack of records
( ) Lack of up-to-date plans and specifications
( ) Lack of emergency plan
( ) Insufficient employee training
( ) No hood testing mechanism
( ) No hood-use approval mechanism

Lab Fume Hood
( ) Improper type for operation/chemicals used
( ) Air leaking from hood (smoke noncontainment)
( ) Surfaces corroded
( ) Surfaces dirty
( ) Hood mechanisms inoperable
( ) Sash broken
( ) Electrical service in hood
( ) Chemical storage in hood
( ) Other storage in hood
( ) Equipment within 6" of face
( ) Lack of real-time airflow monitor
( ) Flammable construction materials
( ) Slots not open to appropriate size
( ) Slots blocked by equipment, chemicals
( ) Open containers in hood during non-use
( ) Use of auxiliary supply at hood face

Hood Operation
( ) Sash not at proper height
( ) Use of hood when hood exhaust off
( ) Hood not being used
( ) Inappropriate chemicals in hood
( ) Noisy

Work practices
( ) Untrained personnel
( ) Rapid movements at hood face
( ) Placing upper body in hood
( ) Use of chemicals outside hood
( ) Use of perchloric acid in unapproved hood

Ductwork
( ) Holes, air leaking
( ) Dents
( ) Poor construction
( ) Plugged
( ) Corroded
( ) Leaking
( ) Dampers improperly set
( ) Fire dampers in exhaust system
( ) Doesn't meet SMACNA qualifications

Fan/Motor
( ) Worn out or corroded
( ) Insufficient rpm
( ) Insufficient horsepower
( ) Belts slipping or broken
( ) Motor burned out
( ) Undersized fan

Stack
( ) Not attached
( ) Inappropriate location
( ) Inadequate height
( ) Stack exist velocity insufficient
( ) Aesthetic enclosure hinders dispersion

Exhaust air
( ) Inadequate exhaust volume
( ) Inadequate face velocity
( ) Inadequate face velocity range
( ) Turbulence in hood face

Form No. 5
Lab Ventilation Deficiency Report Worksheet, page 2

Supply air

( ) No supply air
( ) Insufficient air for dilution of fugitive emissions
( ) Contaminated by exhaust air
( ) Supply diffuser blows on hood face
( ) Supply diffuser blocked
( ) Temperature inadequate
( ) Employee complaints (noise, draft)
( ) Does not meet ASHRAE 62 provisions
( ) Supply not balanced with exhaust

Hood Maintenance

( ) Inadequate maintenance (equipment broken)
( ) Lack of ongoing PM program

Chemical storage cabinets

( ) Cabinet missing doors, panels
( ) Constructed of flammable materials
( ) Mixed acid/solvent/bases
( ) Electrical outlets in cabinet
( ) Lack of approved fire-rated cabinet
( ) Corroded
( ) Dirty
( ) Open containers
( ) Unlabeled containers
( ) No fire extinguisher, or out-of-date

Laboratory

( ) Cluttered, housekeeping poor, dirty
( ) Hood positioned near door, window, walkway
( ) Fire escape routes blocked
( ) Aisles blocked

Manifolded exhaust systems

( ) Likelihood of fire/explosion; mixed chemicals
( ) Corrosion in manifold
( ) Condensation in manifold
( ) One hood goes positive
( ) Part of system under positive pressure

Notes

For more information see Chapters 19, 10, and 5. (c) 1994 D. Jeff Burton

Form No. 6
Duct Design Worksheet

Duct design by the velocity pressure method

ROW		ITEM	SOURCE	UNITS					
1	plans	DUCT ID	plans	FROM--TO					
2		Design Q		cfm					
3		Transport Vel		fpm					
4		Slotted hood?	(yes-row 5; no-row 12)						
5	slots/plenums	Slot Velocity		fpm					
6		Slot Area	(row 2/row 5)	sq ft					
7		Slot VP		in wg					
8		Entry Loss K Factor	(1.78)	--					
9		Acceleration Factor	(1.0)	--					
10		Plenum Loss Factor	(2.78)	--					
11		Plenum SP	(row 7 X row 10)	in wg					
12	ducts	Duct Diameter	Chart #5	inches					
13		Duct Area	Chart #5	sq ft					
14		Duct Velocity	(row 2/row 13)	fpm					
15		Duct VP		in wg					
16		Duct Length	plans	feet					
17		Friction Correction		--					
18		Friction K/100	Chart #5	--					
19	loss factor, K	Friction K	(rows 16x17x18/100)	--					
20		Duct ("Hood") Entry		--					
21		Acceleration	(1.0 at hoods)	--					
22		Elbows		--					
23		Branch Entry		--					
24		System Effect		--					
25		Other	( )	--					
26		Total K	(sum rows 19-25)	--					
27	static pressure	Duct SP	(row 26 X row 15)	in wg					
28		SP at FROM location	(Row 33)	in wg					
29		Jnctn VP change	(at FROM)	in wg					
30		Other SP loss	( )	in wg					
31		Total SP	(sum rows 11, 27-30)	in wg					
32	junction	Is this GOV SP?	plans	(yes/no)					
33		GOV SP	(at TO location)	in wg					
34		Actual Q	(row 2)(rows 33/31)$^{1/2}$	cfm					
35		SPh	(rows 11+(15x(20+21))	in wg					
36		Total Slot Length	plans	ft					
37		Slot width	12X(row 6/row 36)	inch					

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Checklist No. 1
Laboratory Problem Investigation Checklist

☐ Meet with someone knowledgeable about the problem, usually the lab supervisor.
☐ Conduct a quick walk-through survey to become familiar with the general scope of the lab, its occupants and activities. (See Form No. 2).
☐ Review existing paper work (e.g., plans, drawings, OSHA Chemical Hygiene Plan)
☐ Develop a plan for the rest of the investigation; update as needed.
☐ Develop a questionnaire or interview checklist, as appropriate.
☐ Issue questionnaires and/or conduct interviews to determine the nature, scope, extent, and location of the problem.
☐ Characterize existing ventilation systems (e.g., lab hood exhaust systems, the air supply system and any other air handlers.) This might include:
    -- determining types of systems (VAV, Constant volume)
    -- layout
    -- operating and maintenance schedules
    -- controls--types and locations
    -- location and operation of supply registers
    -- flow rates
    -- OA flow rates
    -- mixing, distribution
    -- draft sources at hood face
☐ Summarize your findings and determine potential causes.
☐ Conduct more extensive testing and monitoring as warranted. Compare findings and existing conditions to standards, codes, and good practice.
☐ Determine and test potential control measures, as practical.
☐ Prepare a report with findings and recommendations.
☐ Conduct followup.

For explanatory information, see Chapters 19, 10 1994 D. Jeff Burton

Checklist No. 2
Checklist for the Initial Walk-through Survey of a Lab

☐ **Make Contact**
  - ☐ building manager
  - ☐ person responsible for ventilation system
  - ☐ lab supervisor
  - ☐ employee representative (if applicable)

☐ **Obtain**
  - ☐ list of lab employees or students by job and location
  - ☐ chemical used and stored in the lab
  - ☐ plans and specifications for building
  - ☐ mechanical plans for ventilation systems
  - ☐ maintenance and testing records
  - ☐ OSHA Chemical Hygiene Plan

☐ **Equipment**

☐ Camera
☐ velometer
☐ smoke tubes
☐ ladder
☐ tool kit
☐ pitot tube
☐ indicator tube kit
☐ psychrometer
☐ thermometer
☐ manometer
☐ calculator
☐ lab coat
☐ measuring tape
☐ flash light
☐ paper, pencil, tape recorder
☐ safety equipment (e.g., respirator, goggles)

For explanatory information, see Chapters 5, 10 1994 D. Jeff Burton

Checklist No. 3
Checklist for Safety and Housekeeping*

Lab No. ____________ Date ____________ Investigator ____________

Item — Comments and recommendations

Hood, exterior ____

Hood, interior ____

Air Supply ____

Bench tops ____

Sinks ____

Storage under sinks ____

Chemical storage ____

Aisles ____

Window ledges ____

Walls and floors ____

Chairs, stools, casters ____

Safety glasses, face shields,
protective clothing ____

Fire extinguisher ____

Comp. gas cylinders ____

Broken glassware ____

No smoking policy ____

No food/drink policy ____

Work practices in hood ____

Tubing and hoses ____

Guards and interlocks ____

Eye wash, shower ____

Peroxide-forming chem ____

Lab desks, furniture
and bookshelves ____

Housekeeping ____

Maintenance ____

Electrical services,
wiring, equipment ____

Other ____

Other ____

See also Chapter 4 1994 * Adopted from Reference No. 32.

Checklist No. 4
Checklist for Interviews with Lab Supervisor

- ☐ Find out what the problem is.

  Discuss types and frequencies of lab employee/student complaints.
- ☐ Ask for written documents: drawings, records, testing, building layout.
- ☐ Ask for the OSHA Chemical Hygiene Plan.
- ☐ Obtain ventilation systems operation, testing, and maintenance schedules.
- ☐ Identify the persons in charge of the building ventilation systems; ask for them to be made available.
- ☐ Review and discuss testing and maintenance schedules and procedures.
- ☐ Identify and discuss recent renovations, ventilation modifications.
- ☐ Ask if the person knows the source or cause of the problem; ask what others think may be the source of problem.
- ☐ Ask for all background data already gathered.

For more information, see Chapters 4, 10, and 19 1994 D. Jeff Burton

Checklist No. 5

Checklist for On-site Investigation of Buildings in which a Laboratory is Located

Complaints from non-lab personnel

- ☐ At the *site of the problem or complaint.* Conduct interviews, or distribute questionnaires. Look for obvious sources of the problem. Check temperature, humidity, odors, and carbon dioxide levels. Become familiar with air handling systems. Do complaints relate to chemicals actually used in the lab?
- ☐ Check *parking garages, boiler rooms, incinerators, emergency generator rooms, motor pool areas.* Look for sulfur dioxide, carbon monoxide, carbon dioxide, and nitrogen dioxide. These can be checked with direct reading and inexpensive indicator tubes.
- ☐ Find *locations of building air intakes and exhausts* .
- ☐ Check general *office spaces.* Check carbon dioxide concentrations, temperature, humidity, and formaldehyde with direct reading instruments. Look for visible mold, wet or discolored ceiling tiles, and wet or damp carpet and furnishings. Look for non-lab chemical sources (copiers, cleaning solutions.)
- ☐ Check *mechanical rooms and duct chases.* Look for visible mold, standing wet water, and chemical sources.
- ☐ At *laboratory and chemical storage areas.* Check for fugitive VOC's, spills, open containers, inoperative lab hoods, improper storage practices, air supplies and returns, air path to non-lab sites.
- ☐ Check cafeterias *and food service areas.* Look for decaying organic materials, grease, and other potential sources of odors. Check for carbon monoxide, carbon dioxide, and others as necessary.
- ☐ Check *attics, penthouses, cooling towers, air intake locations.* Look for slime, mold, dead birds, settled water, maintenance, and distance from contaminant sources.
- ☐ Check *designated smoking areas.* Look at the air handling systems. Check carbon monoxide and carbon dioxide.

For more information see Chapters 10, 19   1994   D. Jeff Burton

Checklist No. 6
Laboratory Building Information Checklist

Building: ____________________
Address: ____________________
Date: ____________________
Contact Person ____________________
Telephone: ____________________
Investigator: ____________________
Lab: ____

Building Description:

Year Built
Occupants
Construction
Intake/stack location
Interior Construc.
HVAC type
Owner
No of Floors
Traffic Pattern
Tightness of doors, windows
Interior Layout
Date Occupied
Neighborhood type
Loc. Garages
Insulation type

Laboratory Space Description

Number of people
Lab hoods
Cleanliness
Recent Construction
Temp., Humidity
Adjacent space
Drafts at hood face
Sq.ft/person
Lab hood type
Furnishings
Recent changes
Corrosion
Room pressure
Training
Type of activity
Chemicals present
Construction Mat.
Freestanding fans
Chemical storage
SPh monitor
Stuffiness, lack of air

HVAC and Air Supply Systems

Type of system
Type of fuel
Location of supplies
Terminal velocities
Economizer cycle
Total cfm
Local Exhaust
Water in system
Air Cleaner type
Condition
Type of Diffuser
OA quality
Noise
Controls
Total OA
Makeup air
Type humidifier
Air cleaner effic
Windows
Location OA Intakes
Distribution of air
Dust/dirt/clutter
Zones
Heat exchanger
Duct type
Restroom exhaust
Person in charge

For explanatory information, see Chapters 4, 10 1994 D. Jeff Burton

Checklist No. 7
Laboratory* Air Screening Checklist

Chemical Concern	Typical Background Concentrations**	Equipment
☐ Carbon Dioxide	350-1000 ppm	Indicator tubes, monitors
☐ VOC	<1-5 ppm	Indicator tubes, monitors
☐ Formaldehyde	< 0.1 ppm	Indicator tubes, monitors
☐ Combustion by-products	CO < 10 ppm NO_2 < 1 ppm	Same as above
☐ Particles	< 0.25 mg/m^3	light scattering inst. filter samplers
The following potential contaminants may not originate in the laboratory:		
☐ Bioaerosols	varies (Other Info. more important)	impinger, cascade impacting samplers, bulk samples
☐ Odors	"not obnoxious to occupants"	Identify contaminant first; select accordingly

Typical Performance Standards: Airborne concentrations of chemicals used in the lab should not exceed the Action Level in breathing zone samples of lab workers. The Action Level is chosen by the lab management. Typically, Action Levels are one-half to one-tenth of the OSHA Permissible Exposure LImit (PEL). Area air samples should not exceed the ASHRAE 62 standard, or 10% of the OSHA PEL, whichever is lower.

* Includes both laboratory and lab office spaces.
** Concentrations in excess of these values warrant investigation.

For explanatory information, see Chapters 4, 10 1994 D. Jeff Burton

Checklist No. 8
Checklist for Avoiding Legal Actions

- ☐ Obtain, understand, and follow all laws, regulations, codes, and standards.
- ☐ Comply with ANSI Z9.5 Lab Ventilation Standard.
- ☐ Obtain emission permits for exhaust systems.
- ☐ Develop and implement the OSHA Chemical Hygiene Plan.
- ☐ Adopt a policy of accident and illness "prevention."
- ☐ Take responsibility for laboratory environmental conditions.
- ☐ Involve top management in laboratory health and safety policy and programs.
- ☐ Consult with attorney conversant with laboratory litigation.
- ☐ Become knowledgeable on the subject of laboratory health and safety.
- ☐ Provide monitoring of ventilation systems; maintain records.
- ☐ Seek professional assistance for laboratory problem identification and control.
- ☐ Develop programs which will recognize environmental problems.
- ☐ Address problems at first sign of trouble.
- ☐ Train in-house health and safety personnel; train in-house ventilation personnel.
- ☐ Document all actions taken to avoid/control problems.
- ☐ Provide monitoring programs of employee exposures, air quality.
- ☐ Require and support good lab work practices.
- ☐ Provide education for laboratory users, workers, students.
- ☐ Encourage participation by occupants in lab health and safety programs.

For explanatory information, see Chapter 4 1994 D. Jeff Burton

Checklist No. 9
Laboratory Building Owner's Documentation and Programs*

- ☐ OSHA Chemical Hygiene Plan (CHP) developed and implemented.
- ☐ ANSI Z9.5 Standard for Lab Ventilation complied with.
- ☐ References and calculations for required exhaust through lab fume hoods.
- ☐ References and calculations for required make-up air supplied to labs.
- ☐ Written methods for measuring or monitoring ventilation systems.
- ☐ Description of ventilation control systems.
- ☐ References and calculations for required supply rate of OA to offices and other non-lab areas.
- ☐ Methods for measuring/monitoring OA supply.
- ☐ Description of OA control systems.
- ☐ Description of control systems for VAV systems.
- ☐ Documentation of temperature/humidity control systems.
- ☐ Filtration descriptions and SOPs for use.
- ☐ Filter efficiency documentation.
- ☐ Written testing and preventive maintenance program
- ☐ Testing and maintenance record keeping (e.g., ASHRAE 110 testing results)
- ☐ Written Standard Operating Procedures.
- ☐ Plans, drawings, specifications of building. (As built/As is.)
- ☐ Plans, drawings, specifications of building mechanical systems. (As builts.)
- ☐ Schematic drawings showing locations of all HVAC equipment for nonengineers.
- ☐ Manufacturers literature for all operating equipment.
- ☐ Testing, balancing, and monitoring records.
- ☐ Building permits, stack permits, other applicable licenses/permits.
- ☐ History of changes to HVAC systems, occupancies.
- ☐ Technical information about control systems.
- ☐ Records of complaints.
- ☐ Records of problems and solutions.
- ☐ Lab occupancy records.
- ☐ Training programs and records
- ☐ Standards, codes, and regulations
- ☐ Lab hood testing programs, results, records.
- ☐ Chemicals (used, stored, MSDS)

* Note: In order to assure adequate ventilation, building operators should maintain these minimum programs, records and documents.

For explanatory information, see Chapter 4 1994 D. Jeff Burton

Checklist No. 10
Checklist for Minimizing Lab Ventilation Problems

☐ Maintain exhaust and supply systems in top working condition.
☐ Provide a written operating and maintenance plan for ventilation systems.
☐ Incorporate ventilation policies in the OSHA Chemical Hygiene Plan.

☐ Provide appropriate volumes of exhaust and supply air.
☐ Provide good distribution and mixing of supply air.
☐ Avoid drafts and turbulence at lab fume hood faces.

☐ Restrict smoking to areas with dedicated ventilation systems.
☐ Limit open shelving and other uses of pressed wood.
☐ Use hard surface flooring and walls where possible.

☐ Use lowest temperatures consistent with energy and comfort.
☐ Provide relative humidities of 30-60%.
☐ Use high efficiency filters on HVAC systems (e.g., ASHRAE dust spot efficiency 50-70%) on supply air.

☐ Develop work practices which reduced emissions and exposures.
☐ Lower occupant densities and operation densities in labs.
☐ Train lab users.

☐ Minimize exposure for those in stressful jobs.
☐ Involve professional assistance in ventilation-related problems.
☐ Provide monitoring and testing of systems, air quality.

☐ Eliminate standing or stagnant water in HVAC systems.
☐ Remove contaminated or emitting materials that cannot be controlled.
☐ Comply with all regulations, permit requirements, building codes.

☐ Comply with appropriate standards and good practices.

For explanatory information, see Chapters 4, 19 1994 D. Jeff Burton

Checklist No. 11A
Basic Information Checklist for Supply and HVAC Systems in Laboratories

- ☐ Plans, drawings, specifications, changes
- ☐ The type of supply system (VAV, Constant Volume)
- ☐ Do labs have windows which open?
- ☐ Location of outdoor air intakes.
- ☐ Location of AHUs.
- ☐ Percent OA.
- ☐ How is OA percentage determined?
- ☐ How are each of the following controlled? (automatic, manual, who, when, how):

    - ☐ Fans
    - ☐ OA Damper
    - ☐ Exhaust and SA dampers, fan dampers
    - ☐ Supply diffuser dampers
    - ☐ Humidity
    - ☐ Temperature
    - ☐ Air distribution

- ☐ Type of filtration:

    - ☐ Arrestance/Dust Spot Efficiency/HEPA
    - ☐ Filter maintenance

- ☐ What is the maintenance program for each of the following (frequency, how, who, when):

    - ☐ Fan components
    - ☐ Drive components
    - ☐ Filters
    - ☐ Drain pans, traps, valves, nozzles
    - ☐ Dampers
    - ☐ Controls

For explanatory information, see Chapter 13.

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Checklist No. 11B
Basic Information Checklist for Lab Fume Hood Exhaust Systems

During the design, purchase, or construction of a lab fume hood exhaust system, the following items should be considered:

☐ chemicals to be used
☐ compatible construction materials
☐ operations conducted in the hood
☐ level of training of lab worker
☐ rate of air exhaust, Q
☐ pressure relationships between lab and surrounding areas
☐ acceptable noise levels
☐ minimize horizontal duct runs
☐ drainage connections (duct, hood, fan)
☐ filters, scrubbers, permits
☐ provisions for fire prevention and/or control
☐ equipment failure feedback systems
☐ flow monitors (e.g., hood static pressure measurement)
☐ duct materials (corrosion, fire, high temperature protection)
☐ fan type (usually, centrifugal; see Checklist No. 16)
☐ fan material, spark proof construction
☐ stack height, location
☐ dampers
☐ labels on the hood
☐ standard operating procedures
☐ location of supply air registers remote from hood face
☐ housekeeping, water wash down
☐ ______________________
☐ ______________________

For more information, see Chapters 5, 14, 15, 17, 18

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Checklist No. 12

Checklist for Reviewing Lab Ventilation Plans and Specifications

- ☐ Investigate the background and objectives of the laboratory project.
- ☐ Be sure you understand the scope of the project. What is to be included and why?
- ☐ Obtain latest prints, drawings, specifications (e.g., "as builts," "current.")
- ☐ Look for conciseness and precision. Mark ambiguous phrases, legalese, and repetition.
- ☐ Do the specifications spell out exactly what is wanted? What is expected?
- ☐ Do plans and specifications adhere to appropriate codes, standards, requirements, and policies?
- ☐ Will the designer be able to design, or the contractor build the system from the plans and specifications?
- ☐ Will the project meet your needs if it is built as proposed?

For explanatory information, see Chapter 14 1994 D. Jeff Burton

Checklist No. 13
Lab Workers Checklist of the Ventilation in the Lab

- ☐ Does the lab fume hood actually contain contaminants within the hood?
- ☐ Are all chemical operations conducted within a lab fume hood?
- ☐ Is the hood always on during chemical operations?
- ☐ Can you feel air movement at the hood face?
- ☐ Do lab workers follow appropriate work practices?
- ☐ Does each lab have a source of supply air?
- ☐ Is the supply air actually moving through supply diffusers?
- ☐ Are supply diffusers and grills open? Are they blocked?
- ☐ Is the air distributed throughout the lab space?
- ☐ Do you feel air moving in the lab?
- ☐ Are there "dead spaces" in the laboratory?
- ☐ Does the supply air blow on the hood face?
- ☐ Are there any free-standing fans used in the laboratory?
- ☐ Is the air too hot? Too cold? Too humid? Too cold?
- ☐ Does the supply air smell bad?
- ☐ Does the supply air make you uncomfortable? Sick?
- ☐ What contaminates the air?
- ☐ Are monitors and testing devices (e.g., SPh monitors) in working condition?

For explanatory information, see Chapters 4, 19 1994 D. Jeff Burton

Checklist No. 14
General Checklist for Lab Ventilation Systems

- ☐ Outdoor Air Intakes
  - ☐ Location
  - ☐ Open
  - ☐ Controllable
  - ☐ Outdoor contaminant sources nearby?
  - ☐ Type
  - ☐ Location of exhausts

- ☐ Supply and HVAC Equipment
  - ☐ Intact
  - ☐ Dry
  - ☐ Clean
  - ☐ Smooth running
  - ☐ Filters in place, operating
  - ☐ Slime, mold, dirt, soot

- ☐ Ductwork
  - ☐ Intact, connected
  - ☐ Dry
  - ☐ Balanced

- ☐ Supply Air Diffusers
  - ☐ Open
  - ☐ Set
  - ☐ Air flow correct
  - ☐ Terminal velocities
  - ☐ Air jet profile
  - ☐ Location
  - ☐ Clean
  - ☐ Supply air blowing on hood face
  - ☐ Use of auxiliary-air supplied hood

- ☐ Exhaust hoods
  - ☐ Location
  - ☐ Air movement, drafts
  - ☐ Appropriate face velocities
  - ☐ Appropriate work practices

For explanatory information, see Chapters 10, 19 1994 D. Jeff Burton

Checklist No. 15
Laboratory HVAC and Air Supply Troubleshooting Checklist

------- Typical Problems -------

( ) insufficient make-up air supplied to the lab
( ) improper balance of supply/exhaust systems
( ) Intake dampers inoperative, malfunctioning

( ) supply dampers at incorrect positions
( ) supply terminal diffusers not at correct positions
( ) VAV systems (hood and supply) not balanced

( ) poor distribution of supply air in laboratory space
( ) draftiness—too much supply air, or improper diffuser settings
( ) stuffiness—not enough air delivery, or not delivered properly

( ) improper pressure differences between rooms—doors hard to open
( ) temperature extremes—too hot or too cold
( ) humidity extremes—too dry or too humid

( ) energy conservation has become No. 1 priority
( ) settled water in supply or HVAC systems
( ) testing and monitoring of ventilation systems inadequate

( ) poor filtration—dirt, bugs, pollen in air delivery system
( ) poor system maintenance
( ) insufficient outdoor air (OA) introduced to the supply system

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For explanatory information, see Chapters 13, 19 1994 D. Jeff Burton

Checklist No. 16
Lab Hood Fan Specification Criteria

When specifying a fan, the specifier should be prepared to provide the following information to the fan supplier:

☐ type of fan (usually centrifugal)
☐ air flow rates
☐ fan static and/or fan total pressures

☐ temperature, humidity and/or density of the air (or gas)
☐ dust or aerosol loading, and type of aerosol
☐ chemical type and loading in air

☐ inlet and outlet configurations
☐ wheel type (radial , BC, FC), wheel materials
☐ motor size, type

☐ drive type; drive variability
☐ physical configuration of the fan housing
☐ access to fan housing

☐ bearings and seals
☐ flexible couplings required
☐ noise requirements

☐ mounting and vibration isolation
☐ rain and weather protection
☐ stack requirements

☐ variable speed motors and controls
☐ special construction
☐ non-sparking construction

For more information, see Chapter 18 1994 D. Jeff Burton

Checklist No. 17
Hood Fan Maintenance Checklist

- ☐ Fan brand, model, drive, rpm.
- ☐ Motor type; rated hp, sf, rpm, voltage, amperage.
- ☐ Fan curves, manuf. literature, installation and maintenance records.
- ☐ Same fan as on plans, drawings, specifications.
- ☐ Operating conditions similar to specifications, SOP.
- ☐ Location.
- ☐ Fan assembly intact, clean.
- ☐ Lubrication of bearings to manufacturers specs.
- ☐ Minimal vibration; noise acceptable.
- ☐ No pulsations of air flow.
- ☐ System operating point on fan curve.
- ☐ System effect losses.
- ☐ Weekly check of belts and sheaves for wear, tension, alignment.
- ☐ All belts replaced at same time.
- ☐ Pulley sheave size and adjustment proper.
- ☐ All nuts and bolts tight.
- ☐ Motor and fan mounts tight, intact.
- ☐ Vibration isolators, pads, springs okay.
- ☐ Motor temperature, amperage, and rpm within limits.
- ☐ Electrical connections and insulation okay.
- ☐ Fan direction of rotation okay.
- ☐ Fan wheel mounted correctly.*
- ☐ Fan wheel not worn, dirty.
- ☐ Strainers, traps, drains, valves open or clear.
- ☐ Filters and shaft coolers okay.
- ☐ Cutoff at proper location.
- ☐ Duct vibration isolators mounted correctly (outside of duct at fan inlet, inside or outside duct on fan outlet)
- ☐ Inlet and outlet dampers set properly; controls operative.
- ☐ Motor and fan wipe down to remove dirt, oil, grease.
- ☐ Belt guards appropriate, installed correctly.
- ☐ Stack attached, guyed; rain protection.

*Inspection of internal fan components or fan wheel should be performed only when fan is off and locked out. See Chapter 18 for more information.

SAFETY FIRST

Checklist No. 18
Information and Emergency Phone Numbers

American Chemical Society Health Safety Referral Service 8:00 a.m. to 5:00 pm (EST), toll free Monday thru Friday (not for emergencies)	1-800-227-5558 ext 4511
Chemical Transportation Emergency Center (Chem-Trec), 24-hours per day, toll free	1-800-424-9300
Chem-Trec information and Referral Center, 24-hours per day, toll free	1-800-262-8200
NIOSH Hotline (Health and toxicity Information)	1-800-356-4674
RCRA Hotline (RCRA and Superfund information) Toll free	1-800-424-9346
Fire Department (your local service)	________________
Ambulance Service	________________
Police	________________
Poison Control Center	________________
Doctor or Nurse	________________
Safety/Security Office	________________
Building Operator (ventilation)	________________
Cognizant Person (office and home)	________________

For explanatory information, see Chapter 1 1994 D. Jeff Burton

Sample Specification No. 1

Typical Specifications for a Lab Fume Hood

(See also Reference No. 1 **More Information** for other samples)

1. The fume hood shall be of the "bypass" type. The air bypass shall be located above the hood face opening and forward of the sash when the sash is raised.

2. Bypass air shall pass through the work chamber of the hood.

3. The bypass shall provide a barrier capable of controlling flying debris during an explosion within the hood.

4. The bypass mechanism shall provide an essentially constant air flow rate through the hood at all times. Face velocities shall not increase more than three times the average with the sash any position.

5. The hood shall have a vertical sliding sash. The sash shall be constructed of non-shattering materials mounted in a steel frame.

6. The sash shall be counter balanced with stainless steel cables over ball-bearing pulleys with metal counter weights. The sash shall move freely throughout its range of motion and be capable of stopping at any point and its run. The sash shall be equipped with two finger grips, one on each side of the sash.

7. When in the full-open position, the sash shall be at least 30 inches above the airfoil.

8. The fume hood shall be of the airfoil design type with a foil at he bottom and a taper along both vertical sides of the face opening.

9. The airflow shall be constructed of stainless steel. The sash shall rest on the airfoil when in the down position.

10. The bottom airfoil shall be raised approximately 1 inch above the bench surface.

11. The superstructure of the hood shall be counter-mounted with dimensions not to exceed (insert dimensions, e.g., 65 inches high by 36 inches deep by 60 inches wide), outside dimensions.

12. Interior clear working height shall not be less than 47 inches above the work surface for the full depth of the hood from the interior of the lintel panel to the face of the baffle plenum.

13. The hood shall have a removable baffle with three slots, one near the bench surface, one in the middle, and one at the top of the hood.

14. Hood baffles shall provide a plenum. The plenum shall be provided with a round duct take-off flange of at least (insert number) inches, centered over the plenum. The flange shall be constructed of stainless steel and protrude at least one inch above the surface of the hood.

15. Slots shall be fixed in place, but shall also be adjustable with common tools (e.g., screwdrivers, pliers, wrenches.)

16. All walls shall be of double construction and shall fully enclose structural supports, sash balance mechanisms, and mechanical connections for utilities and service outlets and controls.

17. Access shall be provided for the inspection and maintenance of the sliding sash mechanism and other mechanical services.

18. Materials of construction shall be non-flammable and acid resistant. Exterior surfaces shall be coated with baked enamel.

19. The hood shall be exhausted so as to provide an average velocity of 100 fpm through the face of the hood when the sash is in the wide open position. The velocity across the face shall be uniform, and shall not exceed plus or minus 10 percent of the average at any one position when tested at the manufacturer's plant.

20. The hood shall be capable of meeting the ASHRAE 110 test procedure rating of 4 AM 0.01.

21. The manufacturer shall provide written and documented results of all tests at the time of delivery.

22. Non-flammable chemical storage shall be provided in a base cabinet constructed so as to be compatible with the hood. The interior of the base cabinet shall be lined with a non-flammable, acid resistant material.

(Note: This is only a partial sample of the specifications required when purchasing a hood. Be sure to include all your requirements, in detail.)

Sample Specification No. 2

Sample Paragraphs for Ventilation Management Plans

(to be included in the Chemical Hygiene Plan)

Chemical Hygiene Plan for Laboratory Ventilation(Organization name)

Administrative Provisions

1. OVERVIEW. Laboratory ventilation controls will be used by (organization name) management to ensure a safe and healthy environment for students, faculty, employees, and visitors. Use of exhaust fume hoods is the preferred control method for operations involving hazardous materials which can become airborne. This management plan specifies the administrative and technical standards for use and testing of laboratory ventilation. The requirements apply to all fume hoods and other ventilation systems used for emission control and operator/visitor protection.

2. RESPONSIBILITY. Unless otherwise stated, the Lab Supervisor must ensure that the requirements of these standards are complied with at all times. In this plan the Lab Supervisor (or designated official) is called the "User."

3. REPORTING. All Users will report to (organization name) Management, with copies to Management on an annual basis. Reporting procedures and forms will be furnished by management.

Technical Provisions

1. SCOPE, PURPOSE, AND APPLICATIONS

1.1 SCOPE. This plan sets forth the requirements for the design and operation of laboratory ventilation systems in the laboratories of the (organization name).

1.2 This plan does not apply in the following types of laboratories or hoods:

Laminar Flow Hoods (not for user protection)

1.3. Where this plan conflicts with other standards, the more stringent will govern.

1.4 PURPOSE. The purpose of this plan is to establish minimum requirements and procedures for laboratory ventilation systems which are used to minimize emissions and employee/user/visitor exposures.

1.5 OBJECTIVES. The objectives of the plan are to (1) set forth ventilation requirements which will, in combination with appropriate work practices, achieve safe concentrations of air contaminants, (2) provide academic departments with a guide, and (3) inform the User of information needed by designers.

2.0 REFERENCES. Appropriate standards and codes will be followed by designers and Users of laboratory ventilation.

3.0 DEFINITIONS, TERMS, UNITS

USER. The person responsible for the health and well being of laboratory employees and visitors (e.g., the laboratory supervisor, the laboratory chief, or other designated official.)

LABORATORY. Typically, a research or development facility equipped for study or testing using potentially hazardous materials.

LABORATORY VENTILATION. As used here, ventilation whose primary responsibility is the control of emissions and exposures, as opposed to comfort ventilation systems.

4.0 GENERAL REQUIREMENTS. Each User will establish a local *Laboratory Ventilation Management Program* to assure proper selection, operation, use, and maintenance of laboratory ventilation equipment.

4.1 COGNIZANT PERSON. In each operation using laboratory ventilation systems, the User will designate a "cognizant person." This person will be responsible for day-to-day safe operation of lab ventilation systems. The Cognizant Person will provide information to the User and coordinate activities with Management.

4.2 PERMANENT RECORDS. Permanent records will be maintained for each laboratory ventilation system.

4.3 LABORATORY EXHAUST FUME HOODS. Adequate laboratory fume hoods will be used when there is a likelihood of employee exposure to air contaminants generated by a laboratory activity.

4.4 VOLUME FLOW RATES. The volume flow rate (Q) in a laboratory ventilation system will be sufficient to control air contaminants generated by the activity.

4.5 REPLACEMENT AIR. An air-handling system will be provided to replace exhausted air.

4.6 DILUTION and REPLACEMENT VENTILATION. Dilution ventilation will be provided to control the buildup of fugitive emissions in the laboratory.

4.7 EXHAUST DISCHARGE. Laboratory ventilation exhaust air will be (1) directed to the atmosphere, (2) discharged so as to avoid reentrainment into building air handling systems, and to avoid hazards to the public.

4.8 EXHAUST STACKS. Exhaust stacks will meet appropriate SMACNA and local codes.

4.8.1 DISCHARGE. Exhaust discharge from stacks will (1) be in a vertical-up position, (2) be 10 feet above the adjacent roof line or air intake if within fifty feet, (3) have a discharge velocity sufficient to avoid downwash during local high winds.

4.8.2 ESTHETICS. Esthetics considerations concerning external appearance of the building will not be allowed to overcome the requirements of 4.8.1.

4.9 COMBINING EXHAUST GASES. Two or more exhaust systems may be combined into a single manifold and stack if the following conditions are met: (1) mixing of gases will not result in reaction products likely to cause fire or explosion, excessive corrosion, or excessive condensation, (2) the entire manifold must be maintained under negative pressure at all times.

4.10 HVAC SYSTEMS. HVAC systems will be designed, constructed, and installed with applicable ASHRAE, SMACNA, BOCA, AMCA, and local codes.

4.10.1 PRIORITY. HVAC systems will be compatible with and support laboratory ventilation systems.

4.10.2 RETURN SYSTEMS. HVAC air to laboratory spaces containing laboratory ventilation systems will not be returned to the air handling system for recirculation unless the following provisions are met: Return air meets the return air requirements of ASHRAE 62, AND (1) There are no extremely dangerous or life-threatening materials used in the laboratory, and the concentration of air contaminants generated by a maximum-credible accident will result in exposure concentrations below 20% of appropriate standards; OR (2) return air is both treated and monitored to assure return air contaminant concentrations are below 20% of appropriate standards at all times and under all conditions, and a bypass is provided for diverting contaminated air to the atmosphere when necessary.

4.11 SUPPLY AIR.

4.11.1 VOLUME. The air handling system will supply an equal volume of make-up air to that exhausted, unless a differential pressure must be maintained between the laboratory and adjacent spaces.

4.11.2 DISTRIBUTION. Supply air distribution will be designed, installed, and operated to create terminal velocities at the face of a hood less than 1/2 of the face velocity of the hood.

4.11.3. QUALITY. Supply system air will meet, at a minimum, the requirements of the latest version of ASHRAE 62, Indoor Air Quality.

4.11.4. DIRECTION OF FLOW. As a general rule, air flow will be from areas of low hazard to areas of higher hazard, unless the laboratory is used as a Clean Room of Class 10,000 or better. Where flow from one area to another is critical to emission and exposure control, airflow monitoring devices will be installed to signal or alarm a malfunction.

4.12 PREVENTIVE MAINTENANCE. Each User will establish a preventive maintenance (PM) program for critical components of laboratory ventilation systems, and will perform PM on a regularly scheduled basis.

4.13 TESTING AND MONITORING. Each User will conduct testing, following guidelines established by management.

4.13.1 SCHEDULE. Each User will select and perform testing and monitoring of critical components of laboratory ventilation systems on a regularly scheduled basis. Each hood will be equipped with a real-time monitor of performance, preferably a hood-static pressure monitoring device. Records of testing will be maintained.

4.13.2 EQUIPMENT. All monitoring equipment will be of an appropriate type for the task, and will be calibrated and operated in accordance with the manufacturers recommendations.

4.14 DAMPERS. Where dampers are used for flow control, or for emergency bypass, the User will assure proper settings and operation of damper position, drive linkages, and drive motors. Automatic fire dampers will not be used in laboratory hood ventilation systems.

4.15 ROOM AIR BALANCING. Air volume flow rate, direction of flow, and pressure differentials will be designed and maintained to assure proper function of laboratory ventilation systems.

5.0 LABORATORY EXHAUST FUME HOODS

5.1 MATERIALS. Lab fume hoods will be constructed of noncombustible, nonporous material selected to resist corrosion for the service intended.

5.2 SELECTION. Lab fume hoods will be selected or constructed to minimize emissions and exposures.

5.3 WORK PRACTICES. The User will establish work practices which minimize emissions and exposures.

5.4 PERFORMANCE TESTING. The User will select and adopt appropriate performance tests for each hood, and will conduct such tests as scheduled. As a minimum, each hood will be tested following installation and whenever changes are made to the exhaust system.

5.5 FACE VELOCITIES. Each hood will maintain an average face velocity of 100-125 fpm with no face velocity measurement plus or minus 25% of the average. The User will select an appropriate average hood face velocity for each hood. Conventional hoods (Type S hoods) will be maintained at 100 fpm. High hazard hoods (Type H hoods) will be maintained at 125 fpm. Other hoods (Type E hoods, exempt) will be supplied with face velocities appropriate to use and need.

5.6 FLOW MEASURING DEVICE. New and remodeled hoods will be equipped with a flow-measuring device, i.e., a hood static pressure monitoring device.

5.7 APPROVED FOR USE. Each User will determine performance criteria by which a hood is to be approved for use. Such criteria will be posted at the hood. Following performance testing, a notice of testing results will be posted along with a Use-Approved notice. Hoods not passing performance tests will be approved for use only under special conditions of use which offer equivalent worker protection, and a notice of Conditional-Approval will be posted near the hood. If continued use of the hood puts laboratory workers at unreasonable , the hood will be taken out of service and a Failed notice posted. (See attached notices and labels.)

5.8 RETURNING EXHAUST AIR. Air exhausted from laboratory hoods and other direct contaminant control equipment will not be returned to the laboratory space.

5.9 BYPASS HOODS. Bypass hoods will meet all requirements of Paragraphs 5.1-8. Hoods to be installed at facilities should be of the bypass type.

5.9.1 FACE VELOCITY. As the sash is closed, the average face velocity should never exceed 3X the average face velocity when the sash is in the wide open position.

5.10 VARIABLE VOLUME HOODS. Variable volume hoods will meet all requirements of Paragraphs 5.1-8.

5.10.1. SUPPLY AIR. Variable volume hoods will also modulate supply air to maintain the design pressure differential between the lab and adjacent areas, or if the hood exhaust volume exceeds 10% of the supply volume.

5.11 AUXILIARY-SUPPLIED AIR HOODS. Auxiliary-supplied air hoods will not be used unless special energy conditions require its use. Contact management for guidance.

5.11.1 CONDITIONS OF USE. When auxiliary-supplied air hoods are selected and used, the following provisions will be met: (1) the supply plenum will be located above the top of the hood and external to the hood, (2) the supply jet will be uniformly distributed across the width of the hood, and (3) air flow will be into the hood at all points in the face of the hood.

5.11.2 FACE VELOCITY MEASUREMENTS. The face velocity of the hood will be determined with the supply air turned off.

5.12 PERCHLORIC ACID FUME HOODS. The perchloric acid fume hood will conform to the requirements of Paragraphs 5.1-8 and NFPA 45.

5.12.1 CONDITIONS OF USE. Perchloric acid fume hoods will meet the following provisions: (1) all surfaces of the hood will be materials which will not react with the acid to form flammable/explosive compounds, (2) the entire hood, duct, fan, and stack surface must be equipped with water wash capabilities, (3) ductwork will be stainless steel with smooth-welded seams, (4) the system will not be manifolded or joined to other non-perchloric acid exhaust systems.

5.13 WALK-IN FUME HOOD. Walk-in fume hoods will comply with the requirements of paragraphs 5.1-8, as applicable. The base of the hood will provide for containment of spills by means of a base contiguous with the sidewalls with a vertical lip of at least one inch height, or equivalent.

5.14 GLOVE BOX HOODS. The glove box hood will comply with the requirements of paragraphs 5.1-8, as applicable.

5.14.1 UTILITIES. Utility valves and switches will be external and meet appropriate codes. Where internal control is required, additional valves and switches will be provided.

5.14.2 SPILLS. The glove box will provide for retaining spilled liquids so that the maximum volume of liquid in the glove box will be retained if spilled.

5.14.3 EXHAUST VENTILATION. Exhaust ventilation will be provided and will be capable of maintaining a negative static pressure difference of 0.1 inch w.g. with respect to the room with openings closed, and at least 100 fpm inward face velocity when the largest opening is open, or at the glove port if a glove should fail.

5.14.4 EXHAUST AIR LOCATION. Air exhausted from the glove box should be filtered or scrubbed and discharged to the atmosphere.

Other useful information is provided in the Appendix.

6.0 DUCTWORK. Laboratory ventilation ductwork will comply with appropriate SMACNA Standards. Materials of construction will be compatible with chemicals to be carried in the airstream. Systems and ductwork will be designed so as to maintain a negative pressure in the ductwork inside the building.

7.0 FANS. Fans and air movers will be selected to provide appropriate flow rates and pressures, and will be certified by AMCA. Ductwork connected to fans will avoid "system effect losses" where possible. If not, design will take into account the system effect loss. Fan wheels and housings will be constructed of materials compatible with chemicals being transported in the air through the fan.

8.0 NOISE. Fans, ductwork, and air velocities will be selected which meet noise criteria established by the user, but not to exceed 80 dbA at laboratory user locations.

Second set of Forms/Checklists

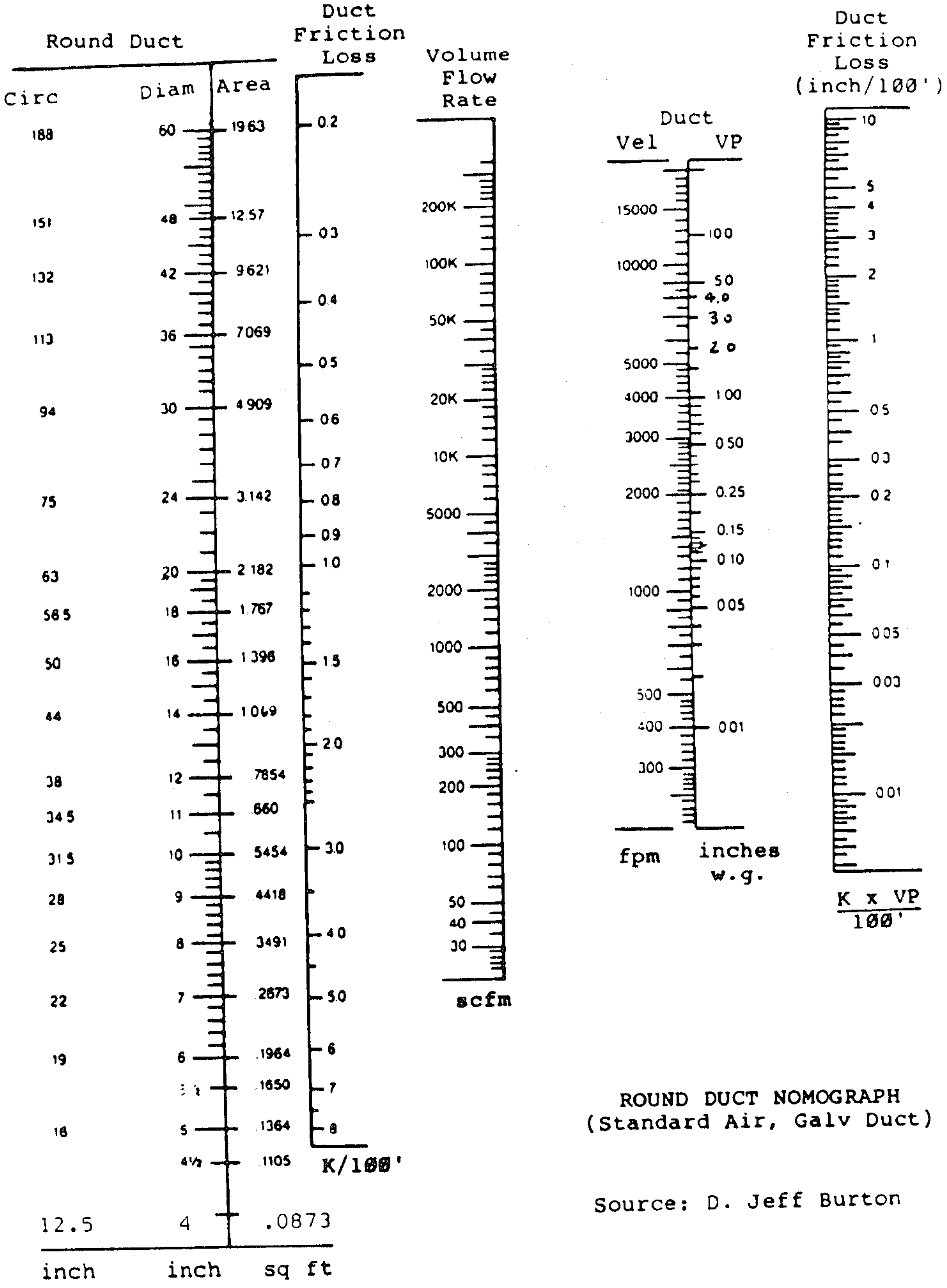
The following checklists and forms are used in *Workbook* Exercises

Chart No.	Topic
5	Round duct flow nomograph

Forms	
1	Laboratory chemical hazard-potential determination
2	Laboratory walk-through survey worksheet
3	Face velocity measurement worksheet
4	Pitot tube traverse worksheet
5	Lab fume hood deficiency report form
6	Duct Design Worksheet

Checklists	
	Investigations
3	Checklist for safety and housekeeping
6	Laboratory building information checklist
	Ventilation
13	Lab users checklist of the ventilation in a lab

Extra Chart No. 5
Round Duct Air Flow Nomogram



ROUND DUCT NOMOGRAPH
(Standard Air, Galv Duct)

Source: D. Jeff Burton

Extra Form No. 1
Laboratory Chemical Hazard-Potential Determination

Evaluator
Name______________ Date __________ Phone number_______________

Lab Contact Name__________Location_______ Phone number__________

Name of chemical_______________________CIS____________________

Type______________________________________ MSDS_______________

Hazard potential (toxicity, fire)______________________________________

Describe physical characteristics:_________________________________
Melting Point__________Boiling Point__________Vapor Pressure_________
Physical State_________Particle Size__________Solubility_______________
Routes of potential exposure__________________TLV/PEL______________
Chemical Hazard Class____
Describe potential exposures:_____________________________________

Quantity of chemical used__________________ Dilution Ratios___________
Frequency of exposure_________________Duration______________________

Describe administrative controls:___________________________________

Lab Fume Hood____

Personal protection ____

Describe required changes:____

For explanatory information, see Chapters 4, 9 1994 D. Jeff Burton

Extra Form No. 2
Laboratory walk-through survey worksheet

Name________________________ Date________________________

Contact______________________ Location______________________

Phone________________________ Lab No. ________________________

Potential Problem	Yes/No	Comments
☐ Lab worker complaints	______	____________________
☐ Hazardous chemicals being used	______	____________________
☐ Corrosion of walls/equipment	______	____________________
☐ Lack of replacement air	______	____________________
☐ Inadequate air distribution in lab	______	____________________
☐ Pressure difference between rooms	______	____________________
☐ Poorly located air supply registers	______	____________________
☐ Drafts at hood face	______	____________________
☐ Detectable odors in lab	______	____________________
☐ Temperature too warm	______	____________________
☐ Temperature too cold	______	____________________
☐ Humidity too high (>60%)	______	____________________
☐ Humidity too low (<30%)	______	____________________
☐ Dirty, organic debris	______	____________________
☐ Visible mold, slime	______	____________________
☐ Water damaged furnishings	______	____________________
☐ Poorly stored chemical containers	______	____________________
☐ Chemicals open on bench	______	____________________
☐ Deteriorated asbestos	______	____________________
☐ Poor maintenance of lab hood	______	____________________
☐ Uncontrolled equipment emissions	______	____________________
☐ Free standing fans in lab	______	____________________
☐ Lab fume hood inoperable	______	____________________
☐ Poor lab hood work practices	______	____________________
☐ Poor work practices, general	______	____________________
☐ Poorly located loading docks	______	____________________
☐ Tobacco/food in lab	______	____________________

For explanatory information, see Chapters 19, 10, and 4 1994 D. Jeff Burton

Extra Form No. 3
Face Velocity Measurement Worksheet

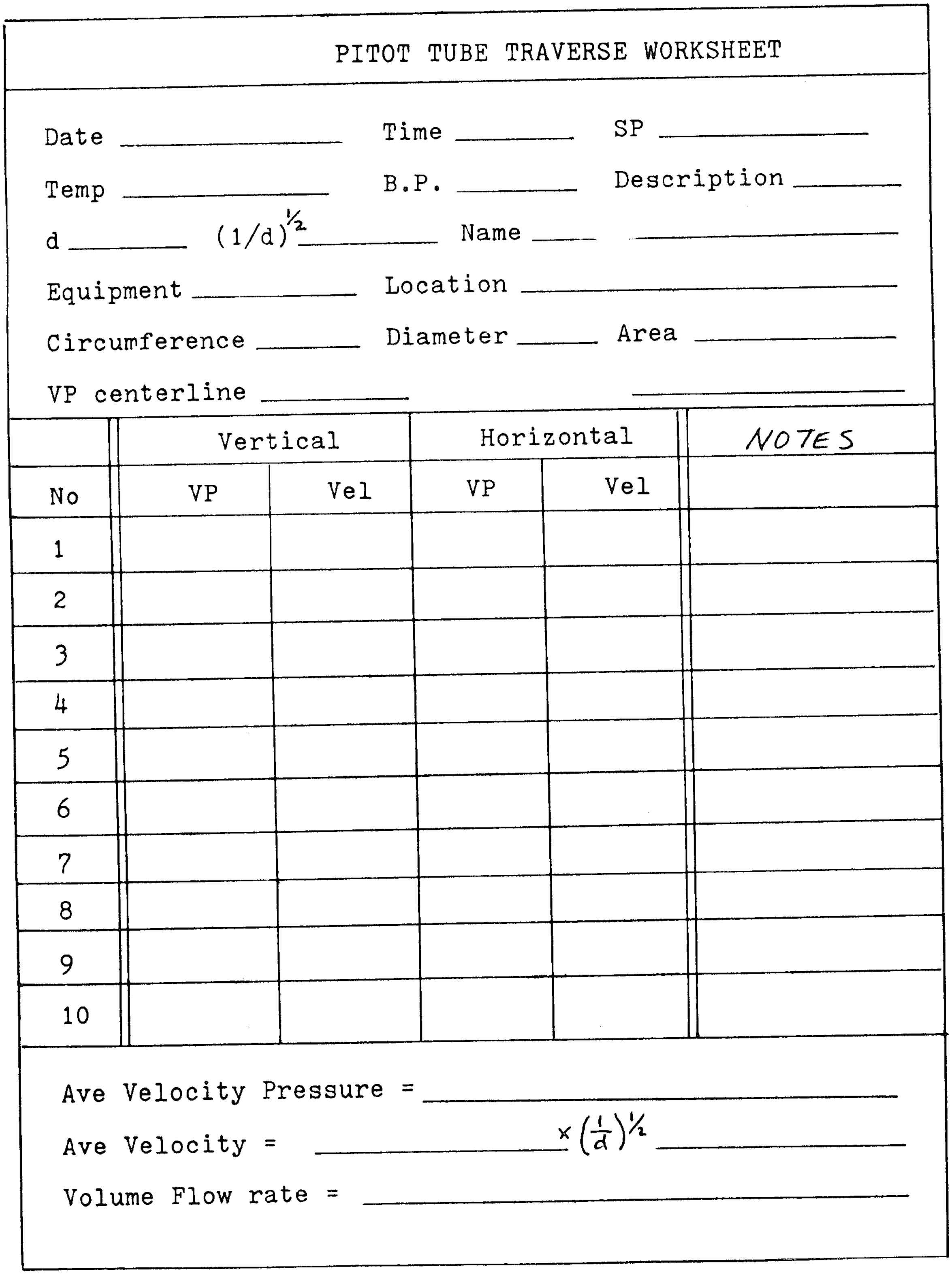
FACE VELOCITY WORKSHEET

Date
Time
Temp
B.P.
Vel. Corr.
Name
Equipment
Location

No.	Vel	No.	Vel	No.	Vel	
1		11		21		
2		12		22		
3		13		23		
4		14		24		
5		15		25		
6		16		26		
7		17		27		
8		18		28		
9		19		29		
10		20		30		

Ave Velocity =
Hood Face Area =
Volume Flow rate =

Extra Form No. 4
Pitot Tube Traverse Worksheet



PITOT TUBE TRAVERSE WORKSHEET

Date ____________ Time ________ SP ____________

Temp ____________ B.P. ________ Description ________

d ________ $(1/d)^{1/2}$ ________ Name ____ ____________

Equipment ____________ Location ____________

Circumference ________ Diameter ______ Area ____________

VP centerline ____________ ____________

	Vertical		Horizontal		NOTES
No	VP	Vel	VP	Vel	
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

Ave Velocity Pressure = ____________

Ave Velocity = ____________ $\times \left(\frac{1}{d}\right)^{1/2}$ ____________

Volume Flow rate = ____________

Extra Form No. 5
Lab Ventilation Deficiency Report Worksheet

Bldg________ Room ________ Hood
Number ____________ Fan Number ______
Date__________ Investigator/Reporter ______

Page 1

Notes:

Management
( ) No local cognizant person
( ) Lack of records
( ) Lack of up-to-date plans and specifications
( ) Lack of emergency plan
( ) Insufficient employee training
( ) No hood testing mechanism
( ) No hood-use approval mechanism

Lab Fume Hood
( ) Improper type for operation/chemicals used
( ) Air leaking from hood (smoke noncontainment)
( ) Surfaces corroded
( ) Surfaces dirty
( ) Hood mechanisms inoperable
( ) Sash broken
( ) Electrical service in hood
( ) Chemical storage in hood
( ) Other storage in hood
( ) Equipment within 6" of face
( ) Lack of real-time airflow monitor
( ) Flammable construction materials
( ) Slots not open to appropriate size
( ) Slots blocked by equipment, chemicals
( ) Open containers in hood during non-use
( ) Use of auxiliary supply at hood face

Hood Operation
( ) Sash not at proper height
( ) Use of hood when hood exhaust off
( ) Hood not being used
( ) Inappropriate chemicals in hood
( ) Noisy

Work practices
( ) Untrained personnel
( ) Rapid movements at hood face
( ) Placing upper body in hood
( ) Use of chemicals outside hood
( ) Use of perchloric acid in unapproved hood

Ductwork
( ) Holes, air leaking
( ) Dents
( ) Poor construction
( ) Plugged
( ) Corroded
( ) Leaking
( ) Dampers improperly set
( ) Fire dampers in exhaust system
( ) Doesn't meet SMACNA qualifications

Fan/Motor
( ) Worn out or corroded
( ) Insufficient rpm
( ) Insufficient horsepower
( ) Belts slipping or broken
( ) Motor burned out
( ) Undersized fan

Stack
( ) Not attached
( ) Inappropriate location
( ) Inadequate height
( ) Stack exist velocity insufficient
( ) Aesthetic enclosure hinders dispersion

Exhaust air
( ) Inadequate exhaust volume
( ) Inadequate face velocity
( ) Inadequate face velocity range
( ) Turbulence in hood face

Extra Form No. 5
Lab Ventilation Deficiency Report Worksheet, page 2

Supply air
- ( ) No supply air
- ( ) Insufficient air for dilution of fugitive emissions
- ( ) Contaminated by exhaust air
- ( ) Supply diffuser blows on hood face
- ( ) Supply diffuser blocked
- ( ) Temperature inadequate
- ( ) Employee complaints (noise, draft)
- ( ) Does not meet ASHRAE 62 provisions
- ( ) Supply not balanced with exhaust

Hood Maintenance
- ( ) Inadequate maintenance (equipment broken)
- ( ) Lack of ongoing PM program

Chemical storage cabinets
- ( ) Cabinet missing doors, panels
- ( ) Constructed of flammable materials
- ( ) Mixed acid/solvent/bases
- ( ) Electrical outlets in cabinet
- ( ) Lack of approved fire-rated cabinet
- ( ) Corroded
- ( ) Dirty
- ( ) Open containers
- ( ) Unlabeled containers
- ( ) No fire extinguisher, or out-of-date

Laboratory
- ( ) Cluttered, housekeeping poor, dirty
- ( ) Hood positioned near door, window, walkway
- ( ) Fire escape routes blocked
- ( ) Aisles blocked

Manifolded exhaust systems
- ( ) Likelihood of fire/explosion; mixed chemicals
- ( ) Corrosion in manifold
- ( ) Condensation in manifold
- ( ) One hood goes positive
- ( ) Part of system under positive pressure

Notes

For more information see Chapters 19, 10, and 5. (c) 1994 D. Jeff Burton

Extra Form No. 6
Duct Design Worksheet*

Duct design by the velocity pressure method

ROW		ITEM	SOURCE	UNITS					
1	plans	DUCT ID	plans	FROM--TO					
2		Design Q		cfm					
3		Transport Vel		fpm					
4		Slotted hood?	(yes-row 5; no-row 12)						
5	slots/plenums	Slot Velocity		fpm					
6		Slot Area	(row 2/row 5)	sq ft					
7		Slot VP		in wg					
8		Entry Loss K Factor	(1.78)	--					
9		Acceleration Factor	(1.0)	--					
10		Plenum Loss Factor	(2.78)	--					
11		Plenum SP	(row 7 X row 10)	in wg					
12	ducts	Duct Diameter	Chart #5	inches					
13		Duct Area	Chart #5	sq ft					
14		Duct Velocity	(row 2/row 13)	fpm					
15		Duct VP		in wg					
16		Duct Length	plans	feet					
17		Friction Correction		--					
18		Friction K/100	Chart #5	--					
19	loss factor, K	Friction K	(rows 16x17x18/100)	--					
20		Duct ("Hood") Entry		--					
21		Acceleration	(1.0 at hoods)	--					
22		Elbows		--					
23		Branch Entry		--					
24		System Effect		--					
25		Other	( )	--					
26		Total K	(sum rows 19-25)	--					
27	static pressure	Duct SP	(row 26 X row 15)	in wg					
28		SP at FROM location	(Row 33)	in wg					
29		Jnctn VP change	(at FROM)	in wg					
30		Other SP loss	( )	in wg					
31		Total SP	(sum rows 11, 27-30)	in wg					
32	junction	Is this GOV SP?	plans	(yes/no)					
33		GOV SP	(at TO location)	in wg					
34		Actual Q	(row 2)(rows 33/31)$^{1/2}$	cfm					
35		SPh	(rows 11+(15x(20+21))	in wg					
36		Total Slot Length	plans	ft					
37		Slot width	12X(row 6/row 36)	inch					

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Extra Checklist No. 3
Checklist for Safety and Housekeeping*

Lab No. ____________ Date __________ Investigator __________

Item | Comments and recommendations

Hood, exterior ______________________________
Hood, interior ______________________________
Air Supply ______________________________
Bench tops ______________________________
Sinks ______________________________
Storage under sinks ______________________________
Chemical storage ______________________________
 Aisles ______________________________
Window ledges ______________________________
Walls and floors ______________________________
Chairs, stools, casters ______________________________
Safety glasses, face shields,
 protective clothing ______________________________
Fire extinguisher ______________________________
Comp. gas cylinders ______________________________
Broken glassware ______________________________
No smoking policy ______________________________
No food/drink policy ______________________________
Work practices in hood ______________________________
Tubing and hoses ______________________________
Guards and interlocks ______________________________
Eye wash, shower ______________________________
Peroxide-forming chem ______________________________
Lab desks, furniture
 and bookshelves ______________________________
Housekeeping ______________________________
Maintenance ______________________________
Electrical services,
 wiring, equipment ______________________________
Other ______________________________
Other ______________________________

See also Chapter 4 1994 * Adopted from Reference No. 32.

Extra Checklist No. 6
Laboratory building information checklist

Building:____________________
Address:____________________
Date: ____________________
Contact Person: __________________
Telephone: ____________________
Investigator: ____________________
Lab: ____

Building Description:

- Year Built
- Occupants
- Construction
- Intake/stack location
- Interior Construc.
- HVAC type
- Owner
- No of Floors
- Traffic Pattern
- Tightness of doors, windows
- Interior Layout
- Date Occupied
- Neighborhood type
- Loc. Garages
- Insulation type

Laboratory Space Description

- Number of people
- Lab hoods
- Cleanliness
- Recent Construction
- Temp., Humidity
- Adjacent space
- Drafts at hood face
- Sq.ft/person
- Lab hood type
- Furnishings
- Recent changes
- Corrosion
- Room pressure
- Stuffiness, lack of air
- Type of activity
- Chemicals present
- Construction Mat.
- Freestanding fans
- Chemical storage
- SPh monitor
- Training

HVAC and Air Supply Systems

- Type of system
- Type of fuel
- Location of supplies
- Terminal velocities
- Economizer cycle
- Total cfm
- Local Exhaust
- Water in system
- Air Cleaner type
- Condition
- Type of Diffuser
- OA quality
- Noise
- Controls
- Total OA
- Makeup air
- Type humidifier
- Air cleaner effic
- Windows
- Location OA Intakes
- Distribution of air
- Dust/dirt/clutter
- Zones
- Heat exchanger
- Duct type
- Restroom exhaust
- Person in charge

For explanatory information, see Chapters 4, 10 1994 D. Jeff Burton

Extra Checklist No. 13
Lab workers checklist of the ventilation in the lab

- ☐ Does the lab fume hood actually contain contaminants within the hood?
- ☐ Are all chemical operations conducted within a lab fume hood?
- ☐ Is the hood always on during chemical operations?
- ☐ Can you feel air movement at the hood face?
- ☐ Do lab workers follow appropriate work practices?
- ☐ Does each lab have a source of supply air?
- ☐ Is the supply air actually moving through supply diffusers?
- ☐ Are supply diffusers and grills open? Are they blocked?
- ☐ Is the air distributed throughout the lab space?
- ☐ Do you feel air moving in the lab?
- ☐ Are there "dead spaces" in the laboratory?
- ☐ Does the supply air blow on the hood face?
- ☐ Are there any free-standing fans used in the laboratory?
- ☐ Is the air too hot? Too cold? Too humid? Too cold?
- ☐ Does the supply air smell bad?
- ☐ Does the supply air make you uncomfortable? Sick?
- ☐ What contaminates the air?
- ☐ Are monitors and testing devices (e.g., SPh monitors) in working condition?

For explanatory information, see Chapters 4, 19 1994 D. Jeff Burton